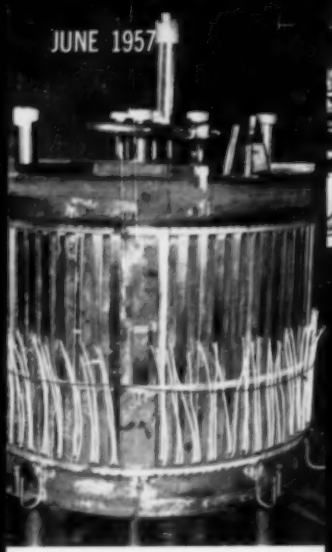
CHEMICAL ENGINEERING PROGRESS

CEP

JUNE 1957



REPROCESSING DILEMMA

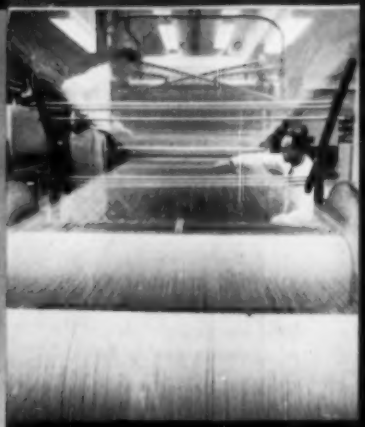
It now appears tbat one nuclear reprocessing plant will serve the utilities for a while. Question is: who will build and operate plant—government or private firm? ALSO (shown above) 1,500° F. nuclear reactor—first announced step in the direction of process heat generation.

ENGINEERS' SALARIES

Another survey adds to the data on what engineers earn. This time, engineers employed by 311 consulting firms reported. Analyzed by grade of responsibility, a greater spread of earnings can be seen in the higher grades.

LOW TEMPERATURE PROCESSING

Greatly increased demand for the gases in air, plus liquefied gaseous fuels for missiles, has opened a wide field of occupation—and further development—for the chemical engineer.

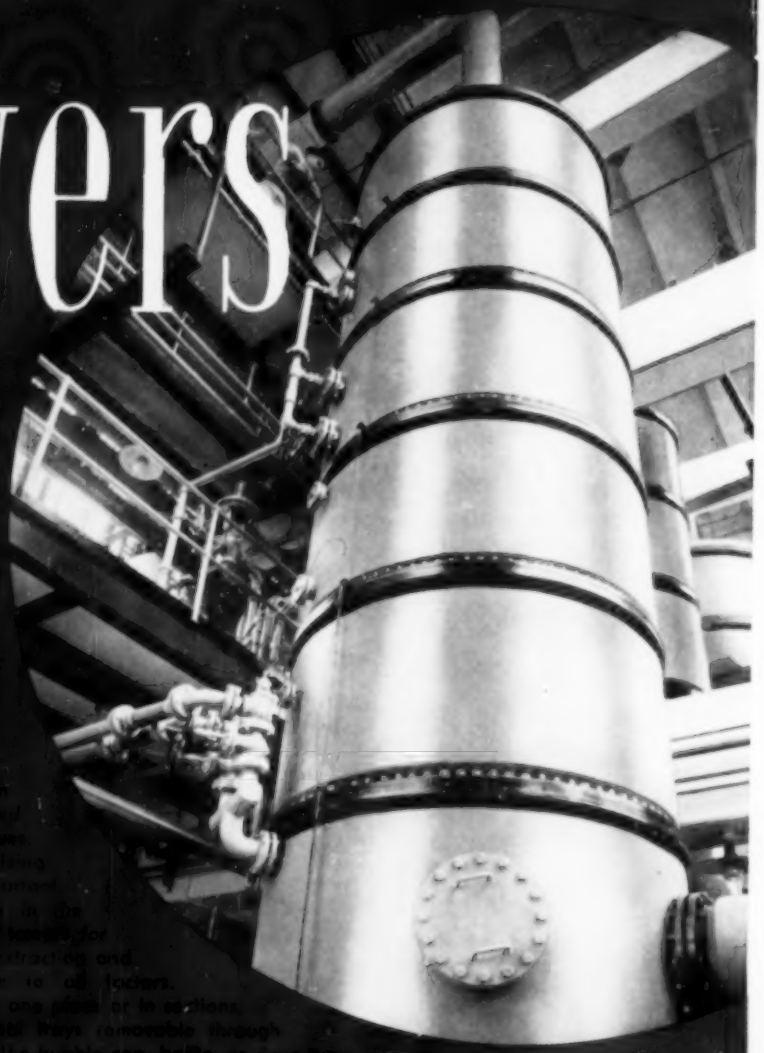


SYNTHETIC FIBERS FUTURE

Processing advances indicate a promising but somewhat turbulent future for synthetic fibers—a field in which the chemical engineer's efforts are rated according to the requirements of a complex art.

Pentaerythritol by mixed catalysts • Investigating plant variables • Spray-drying Na_2SO_4 • Heat transfer economics • Materials—balancing your processes • High energy fuel briefs • Chemical engineer seen as key to industrial pollution control • Testing absorbers.

Towers



VULCAN MANUFACTURING DIVISION

Chemical Engineering Progress

what's in this issue

June, 1957 • Volume 53, No. 6

1,500° F. reactor has been operated / 6
Noted & Quoted—Aircraft reactor experiment described by ORNL Director Alvin M. Weinberg.

Outlet for brainstorms? / 14
Letter to Editor—Reader proposes publication channel for untested ideas.

Nuclear fuel reprocessing dilemma / 19
Edward L. Anderson—Full information has been released by the AEC on new multipurpose reprocessing plant. Question is: Who will build—government or private chemical company?

Project engineering of process plants / 26
Marginal Notes—A new manual on project engineering practice has just been published.

Boron compounds and the chemical industry / 37
Trends—With millions being spent for plants and on boron compound research, the chemical industry can expect exciting new developments.

Era of sources / 259
Opinion & Comment—Rapid developments in applied science fields are providing a variety of new sources for chemical engineering information.

CEP SPECIAL FEATURE

The chemical engineer and low temperatures

The chemical engineer in generation and use of low temperatures / 261
Frank E. Pavlis—Low temperature techniques offer some important new tools with high promise for future development.

Properties of materials at low temperatures (Part 1) / 262
R. J. Corruccini—An outstanding compilation of those properties which are of special importance to the chemical engineer.

Gas prepurification for low temperature processing / 268
N. C. Updegraff—Gas liquefication processes require a prepurification step for removal of troublesome impurities. Review of commercial practice.

Low temperature distillation / 272
Leonard A. Wenzel—A design guide to low temperature distillation practice.

(Continued on page 5)

departmental features

Noted and quoted / 6 • Letters to the editor / 14 • Marginal notes / 26
About our authors / 30 • Opinion and comment / 259 • Date service / 53
Future meetings / 86 • News from local sections / 101 • Candidates for membership / 108 • CEP camera / 110 • People / 112 • Classified / 115
News and notes of A.I.Ch.E. / 124

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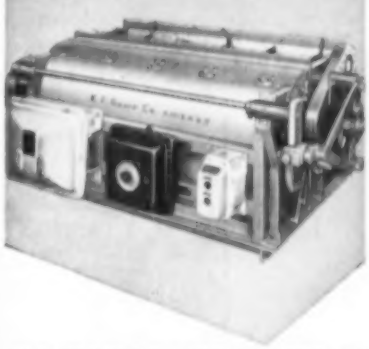

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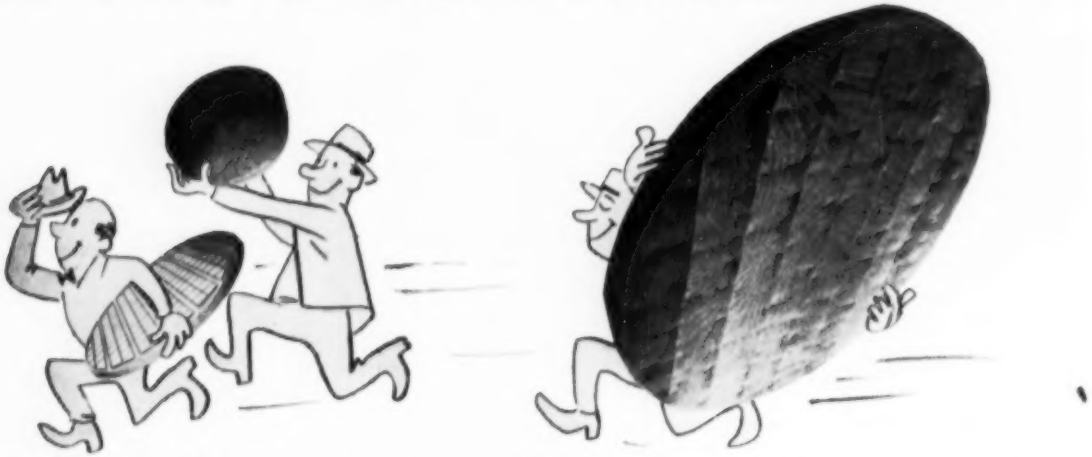

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Cover by *Milton Wynne Associates*

(Continued from page 3)

Low temperature heat exchange / 278
W. E. Gifford—The problems of heat exchange in low temperature operations require special design features.

Drying aqueous sodium sulfate in the jet spray dryer / 282
E. W. Comings, H. A. McLain, and J. E. Myers—The new-design jet spray dryer described in last month's *CEP* is checked out in practical applications.

Heat transfer economics as related to design of nuclear fuel elements / 289
D. Kallman—Correlation of geometric and other design features in fuel elements.

Mixed catalysts in production of pentaerythritol / 293
R. S. Valentine and M. S. Peters—Process data based on pilot plant experimentation.

Material balance in complex and multistage recycle chemical processes / 297
M. F. Nagiev—From Azerbaidjan SSR comes a mathematical method for determining material balance in recycle processes.

Investigating chemical plant process variables / 304
Henry B. Lange—A combination of mechanical and statistical methods used to attack a problem involving trouble shooting and pilot test of a new process.

Synthetic fibers—the future / 307
Frank J. Soday—The new synthetic fibers will depend much upon work by the chemical engineer to correlate processing technology with the desired qualities for end product use.

Boom in boron; rubber suit / 40
Industrial news—Second boron chemicals plant for Callery; Mathieson's $36 million boron fuels plant. Federal Government files suit to gain "natural" rubber process from Goodrich.

Ethylene oxide surge; rubber expansion / 44
Industrial news—Three new 60 million pound ethylene oxide plants will be first to use Shell direct-oxidation process. Former government synthetic rubber plant expanded by 50 per cent after two years in private hands.

Baltimore story: chemical engineers' September oyster / 69
A.I.Ch.E. September meeting in historical Baltimore.

Salary survey of engineers in consulting firms / 76
A new survey of engineers' salaries in 311 consulting firms.

Engineers reject collective bargaining at Minneapolis-Honeywell / 88
Engineers tell why they turned away from union which had represented them for 10 years.

Absorbers put to the test / 98
The story behind A.I.Ch.E.'s new test standard, what it is, what it will do.

CEP camera / 110
May is a month of meetings, as reflected in the eye of *CEP*'s roving cameraman.

Noted and quoted

FIRST REPORT ON 1,500° F. AIRCRAFT EXPERIMENTAL NUCLEAR REACTOR

Alvin M. Weinberg | Director, O.R.N.L., Oak Ridge, Tennessee

High-temperature nuclear reactors hold considerable promise as direct sources of thermal energy for the chemical industry. Earlier this year (February), CEP carried a prediction that a 2,500° F. (exhaust gas temperature) reactor could be built "today." Now, ORNL director Weinberg announces that a 1,500° F. reactor has been built—and operated—at Oak Ridge. Here are Weinberg's remarks, delivered May 15 at the first Inter-American Symposium on Peaceful Applications of Nuclear Energy at Brookhaven.

The Oak Ridge National Laboratory in 1954 performed what was called the Aircraft Reactor Experiment (ARE) which involved a circulating fuel, extremely high-temperature (1,500° F.) reactor in which the fuel was a mixture of molten fluoride salts containing UF_4.

The decision to go ahead with this project was made on the basis that it was worth-while to construct and operate such a reactor even before the difficult problems of long-term metal attack by the fluorides had been solved.

The reactor was designed to operate at 1,500 kw; it actually ran at a peak output of 2,500 kw. The exit temperature of the fuel from the reactor to the heat exchanger was about 1,500° F.; the inlet fuel temperature was about 1,200° F.

The reactor was brought critical on November 3, 1954, by adding a molten UF_4 concentrate to the barren mixture of molten fluoride salts. The reactor went critical essentially without incident, and was brought to full power operation on November 9. The reactor ran continuously for about four days and nights, and after logging more than 90 mw.-hr. of high-power high-temperature operation, it was shut down. The ARE has since been dismantled.

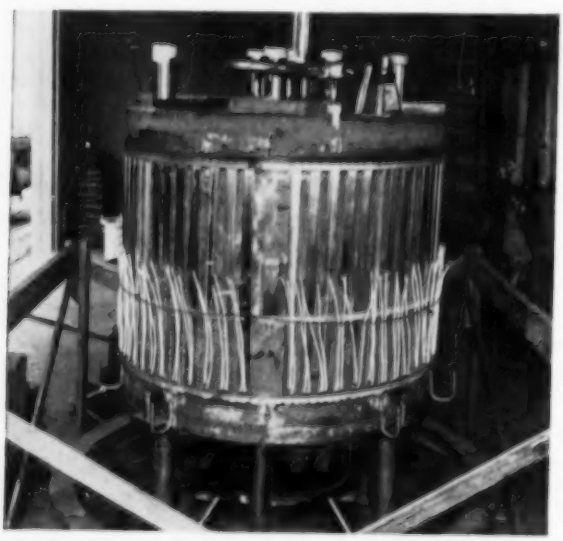
Specifically, the fuel consisted of molten mixtures of the fluorides of uranium and thorium carried in the fluorides of other metals. An example of such a fuel is NaF-BeF_2-UF_4 and of a breeder blanket material, ThF_4-Li_7F-BeF_2. Such fuel allows high temperature at low pressure, dissolves thorium, and does not undergo radiation decomposition.

The fluorides have certain compensating disadvantages. First, the fluoride mixtures melt at rather high temperatures (approximately 500° C.). Second, they are not as good moderators as heavy water—as a consequence the concentration of U^{235} in a fluoride system must exceed the concentration in a heavy-water system, and when the holdup in the external system is counted, the material efficiency of the system tends to be low. Finally, because the fluoride salts used as carriers absorb some neutrons, the breeding ratios achievable in fluoride systems are less favorable than in D_2O systems.

As far as corrosion is concerned, the fluoride systems are entirely different from the aqueous systems since there is no protective film involved. The question of whether corrosion in fluoride systems can be held down sufficiently to allow a molten fluoride reactor to operate for many years is one on which ORNL is now working.

The incentive for achieving a successful high-temperature reactor which burns U^{235} in liquid form is seen from the following economic consideration. If U^{235} costs \$17/g. and if it can be burned without refabrication (i.e., in liquid form) in a very high-temperature reactor with a thermal efficiency of 35%, the fuel cost, just as a straight burner, amounts to less than 2 mils/kw.-hr. This is competitive with the best conventional fuel costs. Thus, the possibility of large-scale conversion of cheap Kentucky and Tennessee coal into cheap electricity, at places far from Kentucky and Tennessee, by first converting the coal to U^{235} in a diffusion plant depends on being able to burn the U^{235} in liquid form in a device which produces the power at high temperatures. In addition, the high temperatures achievable with the molten fluorides make them of interest for aircraft application.

Since the moderating power of the constituents of the fuel was not sufficient to sustain a chain reaction with the U concentrations used, it was necessary to provide a separate BeO moderator. The fuel flowed in serpentine nickel-alloy tubes through the reactor where the system became critical. The liquid was pumped by means of a high-temperature centrifugal pump, and after leaving the reactor, went through a heat exchanger. The heat ultimately was rejected to water; between the fuel system heat exchanger and the water heat exchanger was a stream of recirculating high-velocity helium, which served as an intermediate heat-exchanger fluid. The heat generated in the BeO reflector was removed by circulated sodium; this heat was also rejected to water by means of an intermediate helium system. Because of the thermal expansion of the fuel, the



High-temperature, circulating-fuel reactor, heart of recent Aircraft Reactor Experiment at Oak Ridge.

(*Continued on page* 10)

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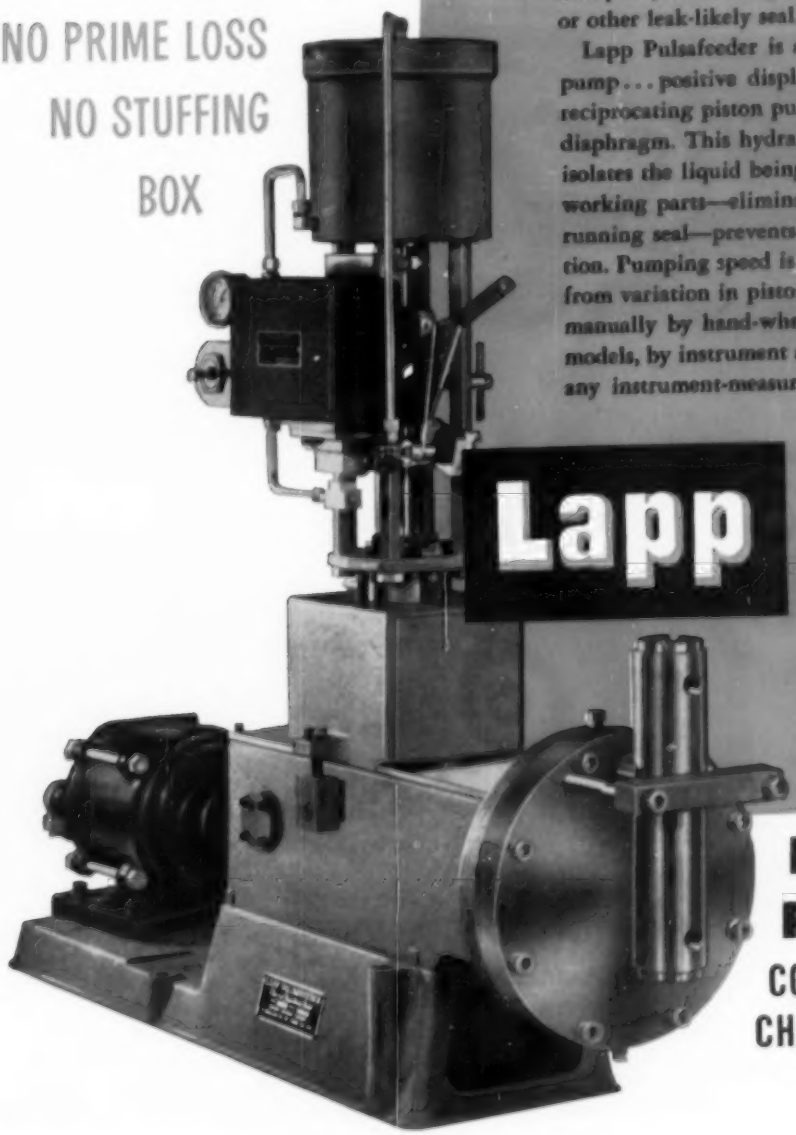

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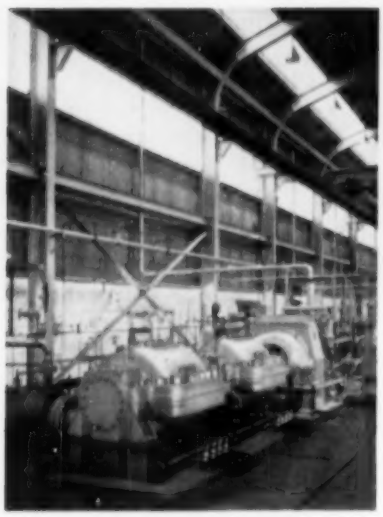

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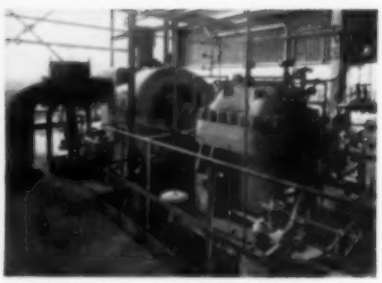

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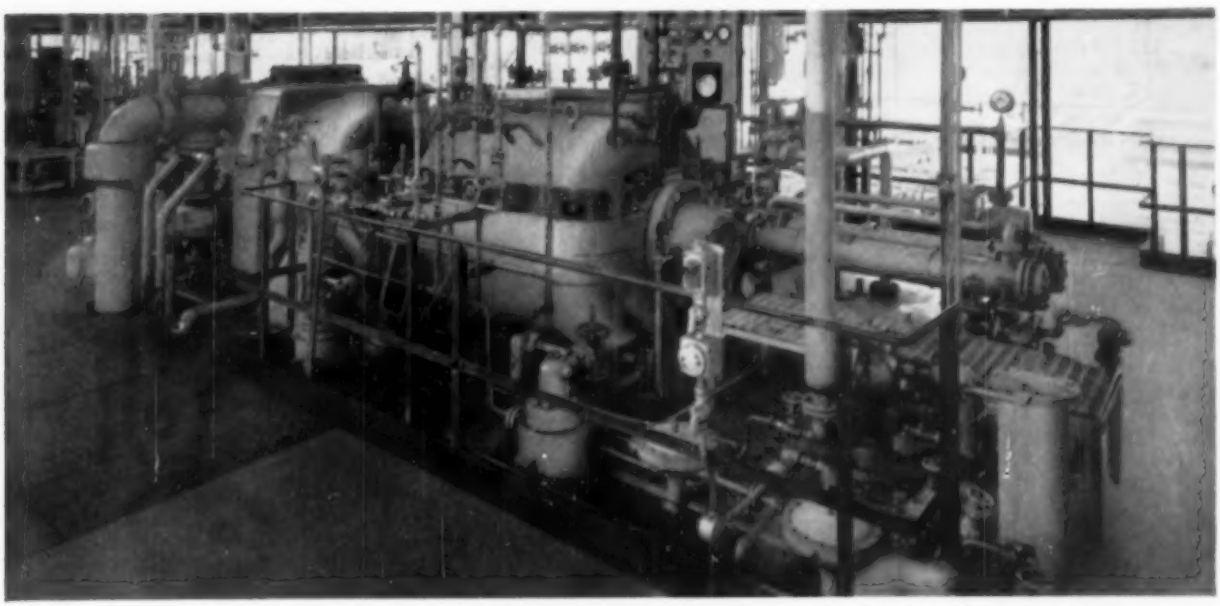

Close-up of I-R gas compressor. Steam turbine driven, rated 19,100 inlet cfm at 76.2 psia discharge. For handling gases from cracking furnaces.

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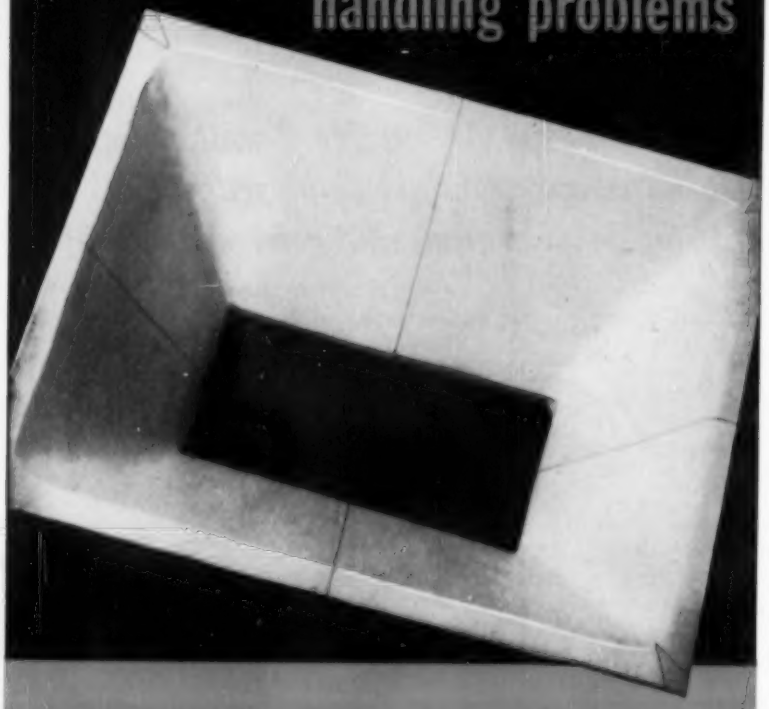

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Noted and quoted

(*Continued from page 6*)

reactor was expected to be entirely self-controlling. The only controls other than the inherent negative temperature coefficient were a stainless steel regulating rod which ran through the center of the reactor and three boron carbide safety rods.

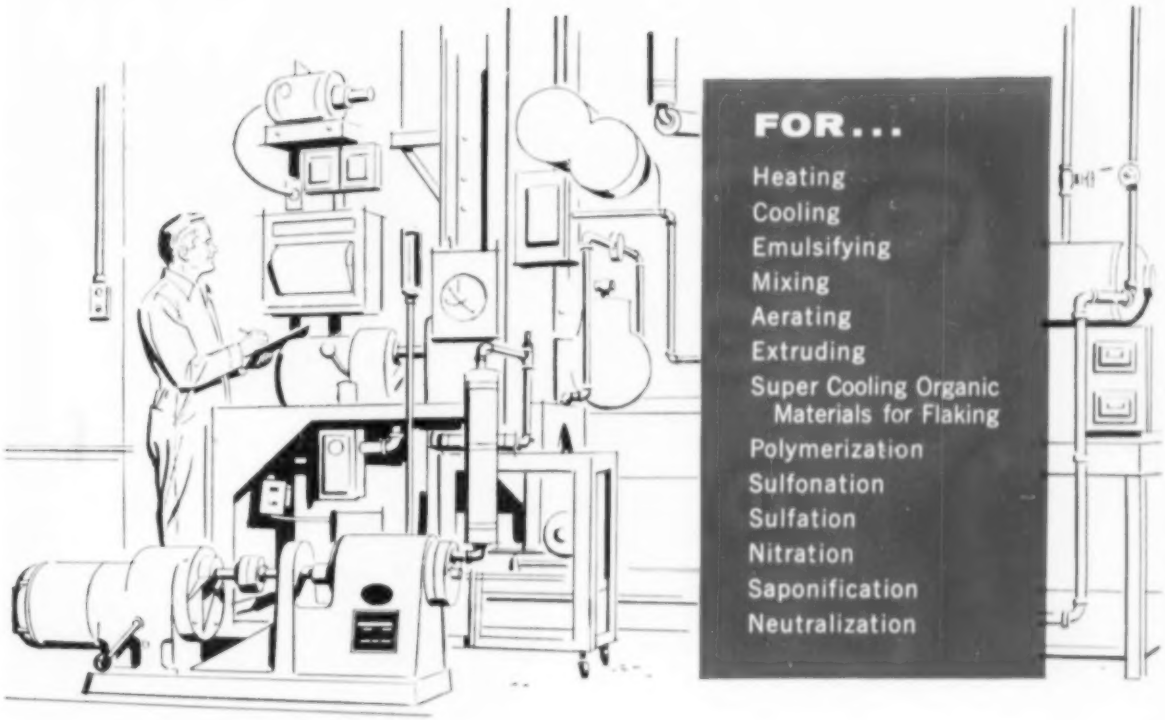
The active region of the reactor was a right circular cylinder, 33.3 in. in diam. and 35.8 in. high. The BeO reflector was 7.4 in. thick. The critical mass was 14.9 kg. of U^{235}; the total mass of U^{235} in the whole system (in core, and external system) was approximately 66 kg. The flow velocity through the reactor was 1 m./sec.; the Reynolds number was 10,000.

Several important observations resulted from our experiences with the ARE:

- The extreme stability of a liquid-fuel reactor was noted. The reactor was completely power-demand responsive, and the control was done mainly by manipulating the flow of cooling helium gas to the heat exchanger. The control rods were used for setting the operating temperature level.
- The Xe^{135} came off continuously, as did many other gaseous fission products.
- The method of keeping the pipes always heated so that no freeze-up would occur was shown to be feasible and practical. This problem in the ARE is rather analogous to the problem of maintaining pressure in the aqueous HRT. It is, so to speak, the price one pays for using a fuel that boils at high temperature.
- As in the HRT, the problem of maintaining absolute leak tightness was difficult. It was solved adequately for the relatively short period of operation of ARE; however, there was a small leak from the gas volume above the liquid surface of the fuel pumps which made the operation awkward during part of the time.

Altogether the experience with ARE reinforces our view that chemical-type reactor systems merit serious investigation, that even a high-melting salt mixture can be used as a reactor fuel, and that one way to achieve economic nuclear power—perhaps the simplest way—is to burn U^{235} in high-temperature devices like ARE in which the fuel is liquid. The Oak Ridge National Laboratory hopes to be able to demonstrate not only short-term operability of such devices, but also long-term reliability of components and compatibility of materials for application in central station, molten fluoride power plants. Success in this venture would open up yet another avenue toward the goal of economic nuclear power.

(*Letters to the Editor on page 14*)



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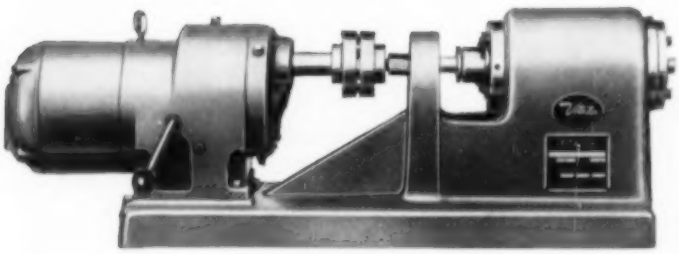

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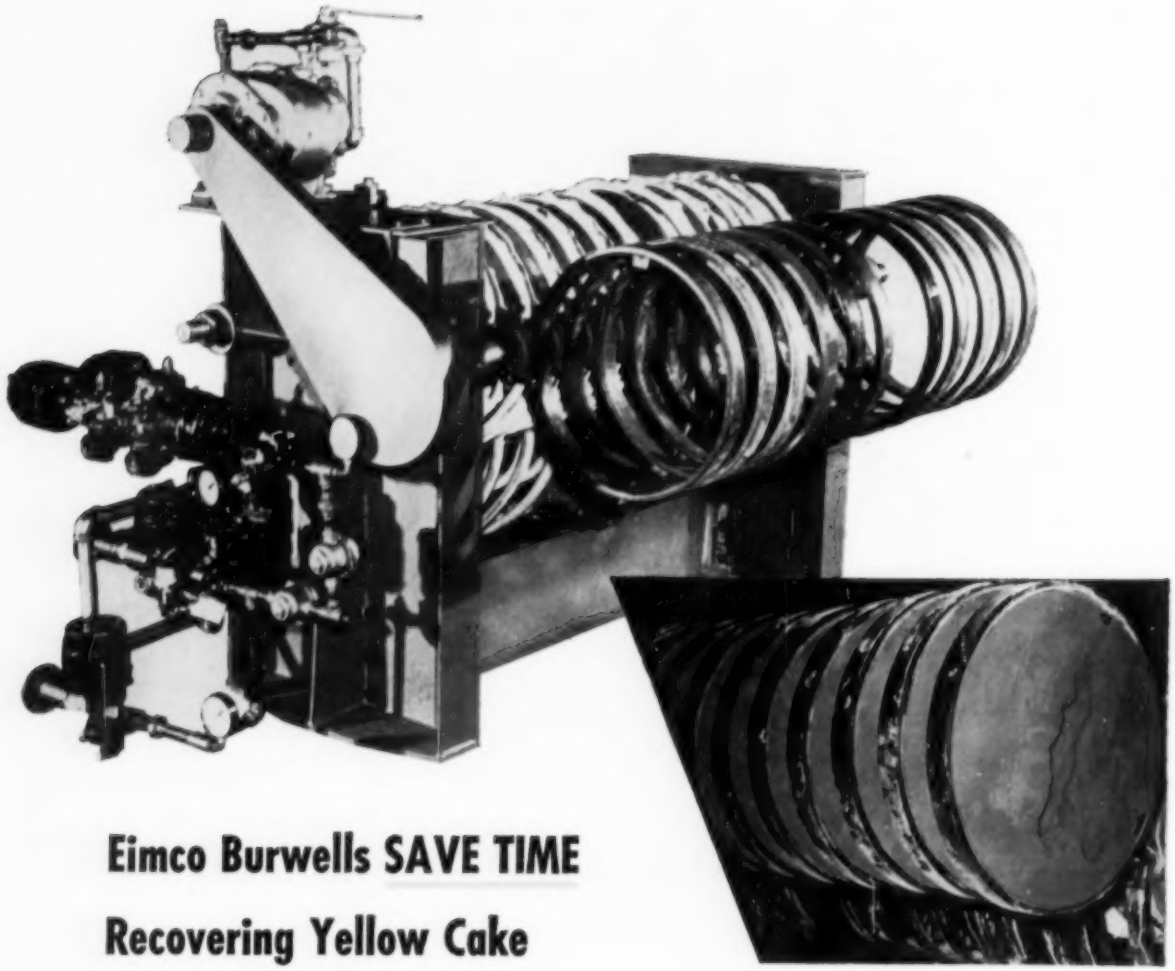

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Washing occurs through half a cake thickness... permits **maximum removal of soluble values with a minimum wash volume.**

One set of frames is filtering while the other is cleaning; thus, **cleaning downtime is negligible.** High mechanical operating efficiency of frames and filters **sharply reduce** labor, maintenance and filter medium costs.

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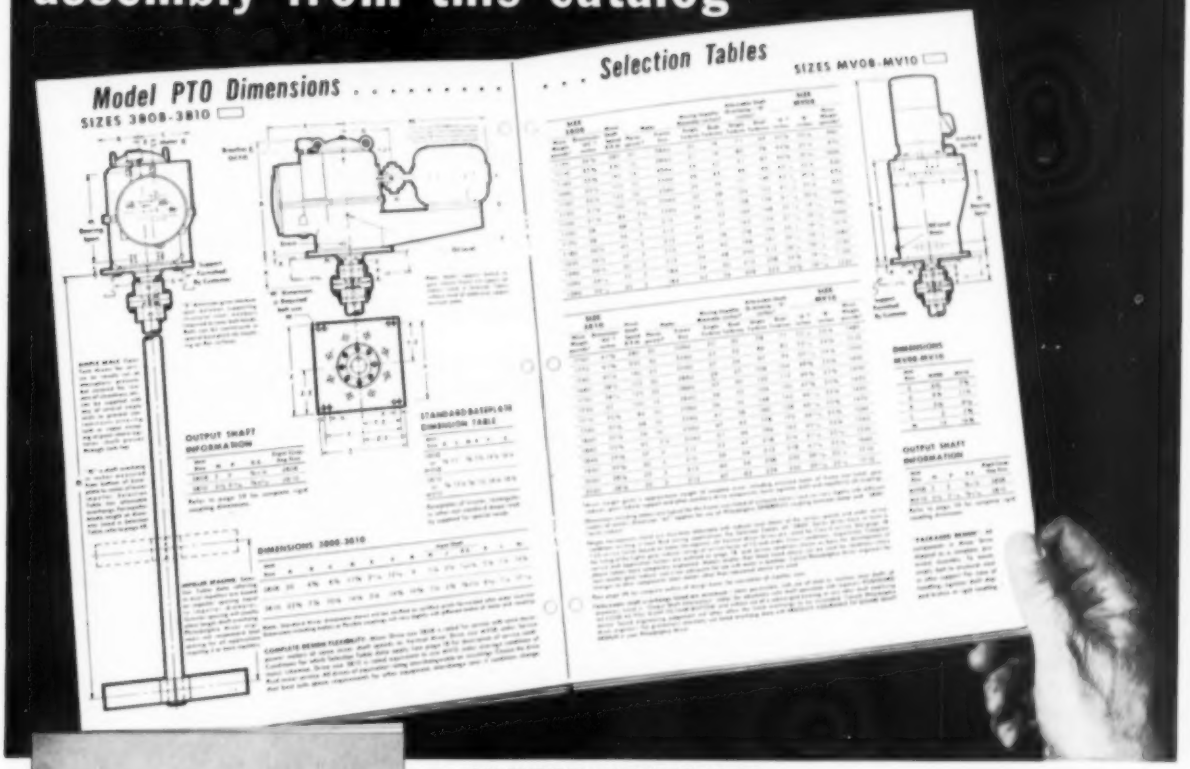

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Letters to the editor

OUTLET FOR BRAINSTORMS?

There is a need for a new and imaginative type of technical magazine feature. Many future developments will come from ideas of people not equipped or not qualified to test them. The current popular and frequently valuable stimulation of imagination produced by science fiction suggests that perhaps there are many more constructive intuitions which could be made by creative people. It is usually speculation which sets us on the path to discovery—prior notions of what we will find before we start our search. "Brainstorming" has demonstrated the value of reducing somewhat the critical testing of ideas before presenting them.

Many major advances in science, broadly defined, have resulted from the cross fertilization of ideas between various fields. This is demonstrated by the names of the fields such as physical chemistry, biochemistry, biophysics. A forum for presenting ideas, curious observations, and unsolved problems should do much toward stimulating the thoughts of really creative people. Such a forum would permit a technical man to ponder over the problems beyond his specialty in the physical or social sciences. According to Norbert Wiener, automation or cybernetics got its start this way. The military people wanted an intelligent antiaircraft gun computer which could learn. Specialists of various disciplines each contributed some ideas—the computer was never built but automation evolved.

The economist might be surprised at what an electrical engineer versed in feedback could suggest about monetary problems—and so might the engineer. Even if an idea is clearly visionary, it may trigger a profitably original line of thought in a reader.

Benjamin Franklin could hardly have published in the scientific journals of today his famous kite experiment or his comments on northeastern storms. His observations were not profound scientific papers but they were major contributions to science. When letter writing was a more polished art than it is today and the people to be reached were fewer, letter writing could serve the purpose. Today more is required. The standards of the current scientific papers should be maintained, but some kind of round table for the less disciplined paper or note should be provided.

Restricting the scope somewhat, perhaps the presentation of an especially perplexing engineering or chemical problem with or without suggested solutions would produce the answer from others with whom contact would otherwise be difficult. The peculiar properties of a material could lead to extensive theorizing about its use, how it would act under various circumstances and the like, and how it might lead to new uses.

What I am suggesting then is an imaginatively edited feature section devoted to speculation—to the presentation of ideas not fully tested, to the stating of problems, and to the asking of stimulating questions. The wider the range of specialties and ideas presented, the more likely it is that they will help create something new under the sun.

One final point seems worth mentioning. From a purely business point of view this seems like an attractive idea. What would be a better place to advertise new products than in a journal which devotes space to imaginative speculation?

Stuart G. McGriff

Callery, Pennsylvania

Why not?—Ed.

Patent Omission

In reading the article "Design of an Ethane Pyrolysis Reactor" by R. H. Snow and H. C. Schutt (*CEP*, March, 1957, p. 133-M), we are distressed to note complete omission of the fact that the thermal cracking furnace described and illustrated is a development of the Selas Corporation of America which development is covered by U. S. Patent No. 2638879.

Elmer B. Dunkak

Dresher, Pennsylvania

Dose of Salts

I have noted on page 190 of the April issue of *Chemical Engineering Progress* an article on electric membrane demineralization. I have not read the article yet, but in general I have no quarrel with Mr. Katz [author]. However, on that page is a box which I am assuming is not Mr. Katz's, but editorial comment. I wish particularly to take exception to Item 2 which is my own particular baby.

In the first place, the International Nickel Company is not constructing this pilot plant; it is being constructed by this organization [W. L. Badger and Associates, Inc.] under a grant from the Department of the Interior.

You say, "It will employ long-tube calandria evaporators similar to those used by salt manufacturing companies." This is a very badly mixed up statement by somebody who knows nothing about evaporators. The long tube evaporators and the calandria evaporators are two totally different designs. The salt industry does not use the long tube design. Consequently, we are not taking a leaf from the book of salt practice. The last sentence in this paragraph is not, strictly speaking, incorrect, but does involve an incorrect inference in that we are not following salt practice at all. So, out of the whole paragraph, the only sentence that is strictly correct is: "The plant is expected to be completed in approximately nine months."

W. L. Badger

Ann Arbor, Michigan

The Uses of Diversity

I extend my appreciation and approval for the excellent performance of your editorial staff in continuing to issue this informative, attractive journal [*Chemical Engineering Progress*]. The discriminating and alert editorial policy is stimulating to engineers in many phases of America's vast technology.

The April issue of *CEP*, which contained a series of articles on the paper industry, was quite useful to a group of about 80 members of our local Oak Ridge-Knoxville Chapter of the A.I.Ch.E., which recently visited the Bowaters Paper Plant at Calhoun, Tennessee.

During a two-hour symposium after the field trip, an enlightening discussion of current paper pulp technology between Bowaters officials and our engineers demonstrated that the engineers were thoroughly familiar with the April *CEP* issue.

C. E. Muzzall

Powell, Tennessee

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Sturtevant blending continues during discharge - no segregation or flotation

Sturtevant Rotary Blenders start 4-way blending while charging, continue it during discharge, thus producing highly intimate, even blends of dry and semi-dry materials — within 3 to 5 minutes of start of charging.

Six *complete* blending cycles per hour are common. And Sturtevant's special action produces no particle reduction, cleavage or attritional heat — is highly effective yet gentle and safe even with explosives.

10 cu. ft. Sturtevant Blender at U.S. Steel Corp.'s new Applied Research Laboratory (Raw Materials Division) in Monroeville, Pa. This unit handles batches up to 500 lbs. — is ideal for pilot work and small runs.

One of four 450 cu. ft. Sturtevant Blenders at Celriver Plant of Celanese Corp. (Rock Hill, N.C.). These large units handle up to 20,000 lbs. batches — have a 9-year record of meeting the most exacting blending requirements.

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Scoops cascade material as drum rotates. Movement forces material from both ends to middle. Thus blending is 4-way — circular, vertical and two lateral.

Discharging

Single gate controls charge, discharge. Blending continues throughout discharge phase. Result is no segregation or flotation — highly intimate, even blends.

Self-cleaning, dust-sealed drum; fast, one-man accessibility

Operation of Sturtevant Blenders is self-cleaning. Drum interiors are completely dust-sealed; special design of stuffing box fully seals against leakage. For inspection of all models, one man simply loosens a few lugs to remove manhole cover — quickly and easily.

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For more on Sturtevant Blenders, request Bulletin No. 080B. (See coupon for available bulletins on other Sturtevant machinery.) Write today.

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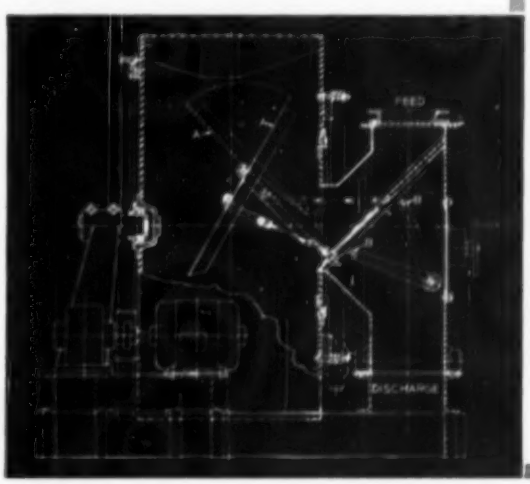
Nine standard models with capacities to 900 cu. ft.

Pilot plant blending to largest production runs are handled by standard models of Sturtevant Blenders with capacities from 10 cu. ft. to 900 cu. ft. Rotary drum design is a proven spacesaver, including headroom. Write for Bulletin No. 080B giving complete specifications.



Sectional view of Sturtevant Blender

'A' (solid line) shows swinging chute in blending position; 'B' (solid line) shows gate closed for blending. 'A' (dotted line) shows swinging chute in discharging position; 'B' (dotted line) shows gate open for discharging.

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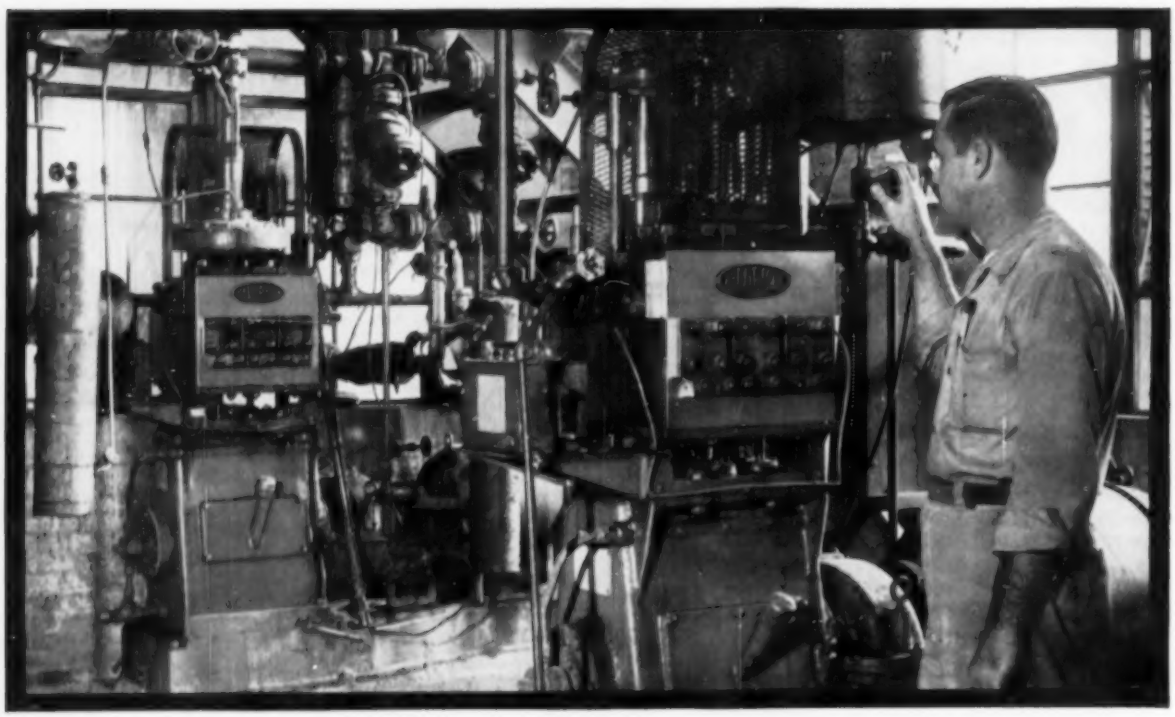
EMERY INDUSTRIES LICKS TOUGH PROBLEM:

How to pump fatty acids 24 hours a day, 7 days a week, and cut maintenance costs!

Around-the-clock hydrolysis produces fatty acids from animal fats, tallow, palm, soybean, cottonseed and corn oils at Emery Industries plant in Cincinnati, Ohio. Pumps work on hot corrosive fatty materials 24 hours a day, seven days a week, and maintenance used to be a costly problem. Packings had to be replaced far too often. Valves needed frequent refacing. Wear of plungers was excessive.



How Emery solved the puzzle: Looking for an answer to the problem of excessive downtime and maintenance, Emery conferred with several pump manufacturers. Aldrich was the only company to offer a pump better in both design and materials . . . the fluid end being of stainless steel. Original, ineffective pumps were immediately replaced with Aldrich Triplex Pumps.

Result: Two Aldrich Pumps have pumped raw materials on a continuous basis since 1948. Two more were installed for additional capacity in 1954. Maintenance costs have been reduced substantially. Downtime has decreased to a minimum. Operating efficiency is now at an all-time high and quality of processing has improved. We'll be glad to send you full information on Aldrich Pumps and their advantages to you. Simply write Aldrich Pump Company, 3 Gordon Street, Allentown, Pa.

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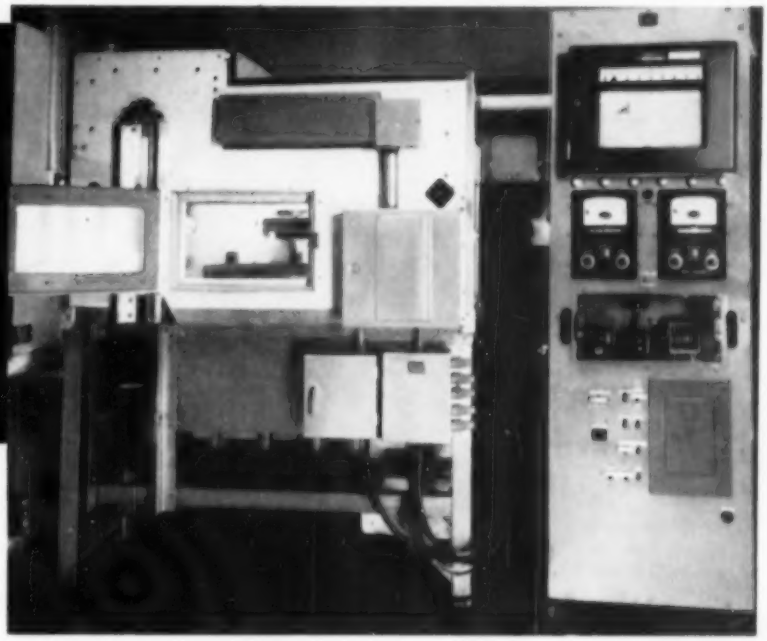
in the WYSSMONT DRYING LABORATORY

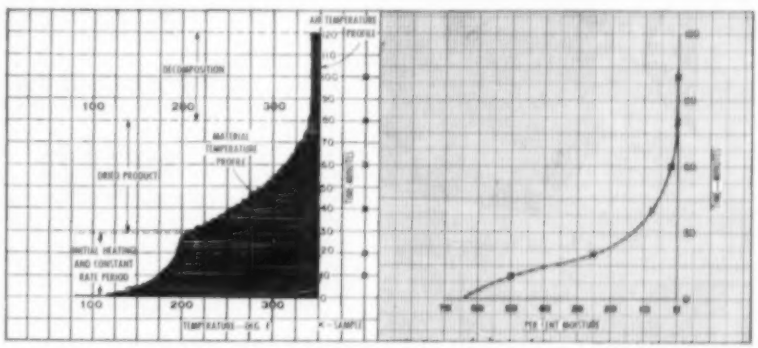


As drying engineers we constantly strive to improve not only our design but also our methods of testing to eliminate guessing. After years of development, we have come up with the last word in laboratory test drying facilities. That is why increasing numbers of manufacturers are calling on the facilities and "know-how" of the Wyssmont drying laboratory to help solve drying problems in connection with products that may be fragile, heat sensitive, oxidizable, toxic, hazardous or otherwise difficult to process.

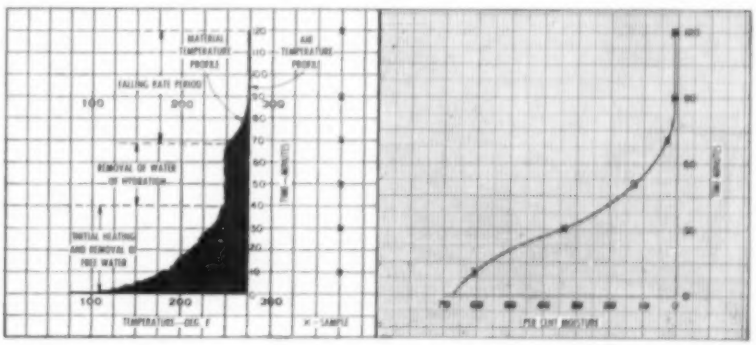
Here in our Wyssmont Test Dryer, simulated actual operating conditions such as material temperature, drying temperature, drying rates, air velocities, turnover cycles are established. These tests are further fortified with complete moisture, chemical and physical determinations. The recording and data are translated into graphs, such as those shown here.

Whether the problem involves drying only, solvent removal and recovery, purification by sublimation or gas-solids reactions, the tests are exhaustive, the product analysis complete and accurate, the report and the conclusions objective and unbiased.

Wyssmont automatic transfer type test dryer with control panel.



Typical record of drying product which sublimes or decomposes.



Typical record of drying a hydrate.

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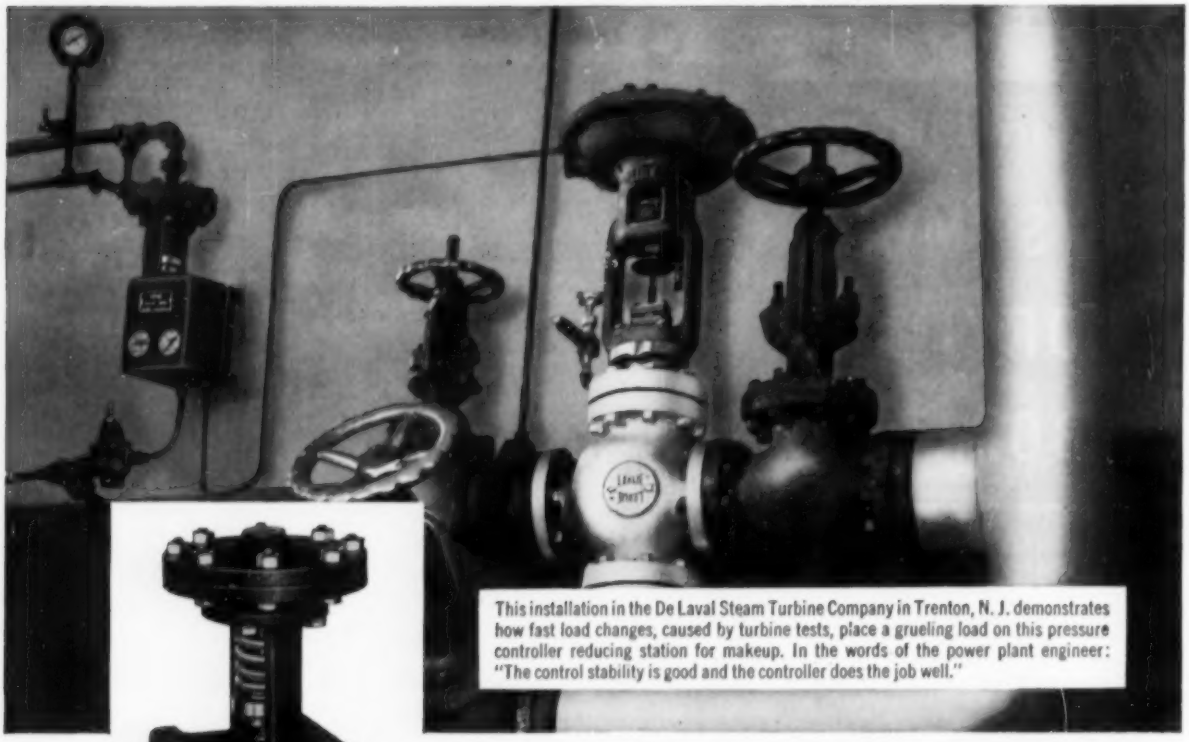

This installation in the De Laval Steam Turbine Company in Trenton, N. J. demonstrates how fast load changes, caused by turbine tests, place a grueling load on this pressure controller reducing station for makeup. In the words of the power plant engineer: "The control stability is good and the controller does the job well."

Leslie Pressure Pilot

Narrow Band Pressure Control *with Stability*

Wide band stability and narrow band proportional control are uniquely combined in the Leslie Control Pilot without need for extra mechanisms to correct for over-sensitivity.

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*not directly related to process variables but resulting from pipeline friction and turbulence.

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Send for Bulletin 5303 that gives complete technical data and typical application sketches for the Leslie Pressure Control Pilot

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NUCLEAR FUEL REPROCESSING — ITS STATUS AND DIRECTION

*Edward L. Anderson, Jr.** | Division of Reactor Development
Atomic Energy Commission, Washington

This magazine has consistently reported the technical background of chemical reprocessing. In the earlier part of the year, the Atomic Energy Commission attempted to define one of the important areas in commercial reactor development that still remained uncertain. Previous releases of price schedules, use-charges, etc., had defined fairly closely the economics, as well as could be seen, of most portions of the nuclear-fuel cycle which were still subject to Commission control. The area remaining was that of nuclear fuel reprocessing—what charges would a power reactor operator incur in that portion of the fuel cycle between the discharge of irradiated fuel and the return of decontaminated fissile and fertile material?

On February 18, 1957, the Commission announced that individually negotiated contracts with private power groups would establish firm charges for Commission processing services subject to cancellation, on a 12-month notice, upon determination that the services were commercially available at a reasonable price. The total charges are to be determined on the basis of a daily charge derived from the costs associated with an assumed chemical-processing plant capable of handling the fuel in question.

It should be emphasized that the use of this hypothetical plant for cost estimation purposes does not necessarily bear any relation to what the Commission will *actually* do with the fuels returned to it. In practice, such a plant could be built, existing facilities could be modified, or selected fuels could be stored indefinitely before processing. The hypothetical plant has been designated the Multipurpose Chemical Processing Plant. The general plant design was synthesized, with respect to order of magnitude, from the technological information available from operating plant data and advanced processing development work. On the basis of anticipated fuel load from power reactors in the period 1960-67, a capacity was determined, assuming that both high and low enrichment material would be processed in the same facility. This saving is possible due to the relatively low capacity for low-enriched material required in this period, approximately 1 ton/day. Under these conditions, equipment size of some of the dissolvers, and columns, is still small enough to permit simultaneous use of enriched material under, for example, always-safe geometry conditions with little or no special design. Where necessary, dual equipment would be installed. The "headend" concept was assumed, the minimum number of headends being chosen which would be capable of handling the diversity of fuel types anticipated as complicated by their different enrichments.

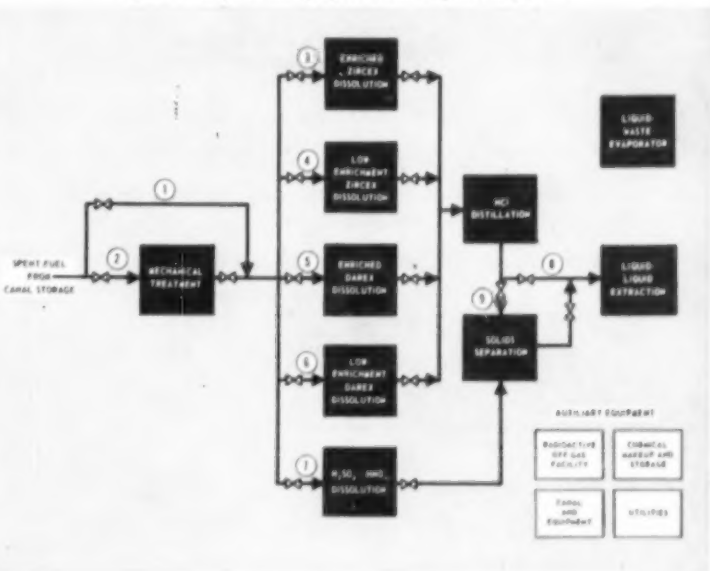
For this purpose, advanced technology was used, in the sense that none of the proposed technologies has as yet been demonstrated in a pilot plant operation with irradiated fuels. However, it should be emphasized that the chemistry and engineering involved are a logical extrapolation of existing technology, and one that *the AEC itself might actually use in the event that private facilities do not become available and processing must be performed on an interim basis in government facilities.*† Some of the technology, particularly that with respect to fuel storage and "tailend" or final cycle solvent extraction, has a sound basis in existing experience.

Figure 1 shows a box flow diagram of the conceptual plant.

Spent fuel, which has been stored in the canal facility pending accumulation of a significant batch or to permit further cooling, is taken either to the appropriate mechanical pretreatment step or directly to the headend dissolution step. The Zircex and Darex headends are tied to a common hydrochloric acid removal step because, as one will recall (*1*), each involves at one stage in the process a solution of hydrochloric and nitric acids—Zircex from the dissolution of the nonvolatile UCl_4 in nitric acid, and Darex from the direct dissolution of stainless materials in a nitric-hydrochloric mixture. The fifth headend was based on the best estimate of how to handle a molybdenum-uranium highly enriched alloy, clad in zirconium with associated stainless steel structural pieces. With this particular design, the stainless was assumed not separable by mechanical means and a preliminary sulfuric acid step was used. The zirconium cladding next was dissolved in pure hydrofluoric acid under which conditions little core material is soluble, and then the core itself was dissolved in nitric acid. Molyb-

† Editor's italics.

Fig. 1. Conceptual multipurpose chemical processing plant.



* Mr. Anderson is chemical engineer in the Engineering Development Branch.

Fig. 2.—Conceptual Multipurpose Chemical Processing Plant

I. Labor and materials		
A. Canal and equipment	$ 750,000	
B. Mechanical treating equipment	540,000	
C. Chemical make-up and storage	270,000	
D. Radioactive off-gas facility	900,000	
E. Prorated utilities	770,000	
F. Waste evaporator	75,000	
G. Liquid-liquid extraction	1,605,000	
H. Enriched Zircex dissolution	480,000	
I. Low-enrichment Zircex dissolution	150,000	
J. Enriched Darex dissolution	150,000	
K. Low-enrichment Darex dissolution	360,000	
L. H_2SO_4-HNO_3-HF dissolution	1,260,000	
M. HCl distillation	900,000	
N. Solids separation	180,000	
O. Buildings	4,837,000	
Total labor and materials		13,227,000
II. Construction overhead and fee (40%)	5,291,000	
Subtotal		18,518,000
III. Engineering and inspection (10%)	1,852,000	
		20,370,000
IV. Product containers	200,000	
Grand total capital		$20,570,000

Fig. 3.—Annual Operating and Waste Storage Costs, Conceptual Multipurpose Chemical Processing Plant

Direct operating personnel and supervision (53 @ $7,200)	$382,000	
Maintenance	130,000	
Supplies	170,000	
Analytical services	102,000	
Health physics	36,000	
Services		
Steam	72,000	
Air	8,000	
Electricity	22,000	
Water	20,000	
Subtotal		942,000
Overhead and other	467,000	
Total operating		1,409,000
Waste storage	527,000	
Total operating and waste		$1,936,000

Fig. 4.—Derivation of AEC Standard Daily Chemical Processing Charge

Annual depreciation (@ 10%)	$2,057,000	
Annual operating and waste storage	1,936,000	
Subtotal		$3,993,000
Annual AEC overhead	599,000	
Total annual costs		4,592,000
Standard AEC daily charge (300 days/year)		$ 15,300

Fig. 6.—Typical Fuel-Processing Charges

Fuel number	1	2	3
Assumed batch size (Kg. U)	12	5,475	22,000
Processing rate (Kg. U/day)	44	150	1,000
Processing time (days)	0.3	36.5	22
Turnaround time (days)	3	8	8
Total plant time (days)	3.3	44.5	30
Processing charge ($000)	50.5	681	459
Unit charge ($/Kg. U)	4,200	124	21

Fig. 5.—Typical Fuel Characteristics and Processing Details

Number and description of fuel	Processing scheme	Rate of dissolution (Kg. U/day)	Rate of extraction (Kg. U/day)
1. Plate assemblies of 90% enriched U as a Zr alloy, Zr clad.	1. Mechanical treatment 2. Enriched Zircex 3. HCl distillation 4. Waste evaporation	4	44
2. Pin assemblies of 27% enriched U as a 10% Mo alloy, Zr clad; S.S. structural material.	1. Mechanical treatment 2. $H_2SO_4 \rightarrow HF \rightarrow HNO_3$ 3. Solids separation	150	150
3. UO_2 pellets (2.5% enriched) in S.S. tubular assemblies.	1. Mechanical treatment 2. Low enrichment Darex 3. HCl distillation	1,000	1,000

denum precipitates in this solution and is centrifuged out before the extraction step. It is undoubtedly fair to say that the fuel element, as recently modified, is somewhat simpler to handle. After either the hydrochloric acid removal or the solid separation step, all materials have been reduced to an all-nitrate form and are amenable to conventional solvent extraction.

The box (Figure 1), "radioactive off-gas facility," indicates the treatment facilities required to overcome any possible hazard to the public from the release of undiluted radioactive krypton, iodine, or volatile ruthenium. These substances can be released in the fuel dissolution step although the total quantities involved are significantly affected by cooling time and specific process technology.

The assumed capital costs of the Multipurpose Chemical Processing Plant, based on existing AEC experience, are shown in Figure 2.

The building is visualized as composed of appropriate concrete cells, each cell housing one or more specific items of process equipment with the associated piping and shielding. Direct maintenance was assumed, based on the highly successful experience obtained at the Idaho Chemical Processing Plant with this technique. Remote maintenance, of the type used at the other AEC processing facilities, was felt to be less desirable for this low throughput, nonroutine plant.

While it was obviously not possible to estimate in detail the costs of many of the individual process items in view of the early stage of development of some of the concepts, this limitation is not felt to be quite so significant as at first might be imagined. Costs of a dissolver and its cell, for example, are not influenced too strongly by the specific material of construction. Only about 20% of the plant cost applicable to a given cell is associated with equipment items. The remainder is determined by over-all cell size and the prorated share of auxiliary facilities such as general piping, analytical facilities, and services. By the application of overhead and engineering fees, a total capital investment of about $20,500,000 results.

Estimated annual operating and waste-storage costs for the plant are shown in Figure 3. Charges for operating personnel, maintenance, and supplies are the best estimates available. Charges for analytical, health, and general services are deduced from the appropriate prorated charge as determined by the local contractor and the AEC at the operating site. Overhead includes administration, and security forces.

Waste-storage technology has been assumed on the basis of the best avail-

able data from current operations, and not from the viewpoint of ultimate disposal, that is, the actual return to the environment of the waste products. Costs were estimated on the basis of the initial construction costs of storage tanks assuming $1.00/gal. for nitric acid, $2.00/gal. for sulfuric acid, and $3.00/gal. for hydrofluoric acid wastes. A charge of 10 cents/lb. was made for $ZrCl_4$ storage. The total waste costs anticipated in an average year, considering each fuel with its appropriate storage volume and charge, were totaled and regarded as an operating cost. This number, plus the other operating expenses, are taken as the total annual operating cost.

The derivation of the AEC standard daily chemical processing charge is shown in Figure 4. In actual practice each fuel processed uses only a portion of the entire plant and the individual operating costs vary from fuel to fuel. Estimates were first made associating with each fuel its proportionate share of total capital costs and its individual operating expense. It soon became apparent, however, that these totaled costs for each fuel were the same within the limits of accuracy of the figures. For this reason, the same daily charge was taken for each fuel. Taking plant depreciation at 10%/yr. and including operating, waste storage, and the standard AEC overhead charges, one finds that a total annual operating expense of about $4,600,000 results. On the assumption of an annual operating basis of 300 days/yr., a daily charge of $13,300/day finally appears. This charge will be modified for any fuel which is found to require significantly higher or lower operating or proportionate capital charges.

In an estimate of the charges for a given fuel, the most important item is the actual throughput rate for the material. Throughput rate is governed by the quantity per day processable through the tailend solvent-extraction facility. This rate may be quite different from that at which the fuel is dissolved or pretreated. Due to the design of the multiple headend facilities, it is possible to carry out several headend operations on different fuels simultaneously. This throughput, plus time for plant cleanup and "turnaround," determines the total number of plant operating days required.

Turnaround time takes into consideration the time necessary for starting, shutdown, and cleanup of the tailend preparatory to introduction of the next fuel. It has been taken as either eight days or, for small batches of fuel, equal to the actual processing time, with a minimum of three days in any case. This sliding scale was chosen to reflect economies which might result, in the treatment of small batches, from special scheduling or deliberate mixing of material of different enrichments. The desirability of blending different enrichments and the optimization of process losses will be determined purely on an economic basis using the published price scales for nuclear materials.

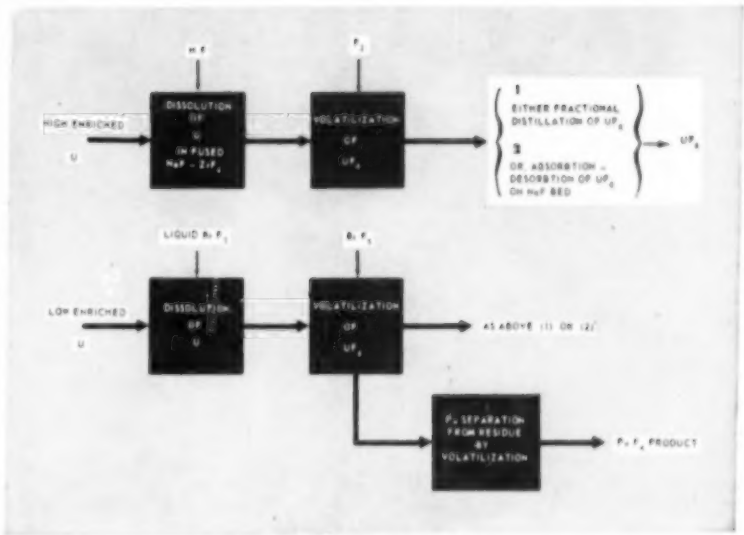


Fig. 7. Volatility processing.

The AEC plans to release additional information on the plant design and flowsheets in the near future so that private operators can make their own preliminary estimates of charges for fuels of the more common varieties. Estimates for charges on fuel of new compositions or unusual design would presumably have to be made by the Commission inasmuch as plant modifications or new flowsheets might be required. The charge covers only the treatment of fuel; it does not include process losses or use-charge during processing. Losses will be taken as 1% of the feed. Costs of delivery of fuel to the processing plant would be borne by the reactor operator.

The technology behind the derivation of charges for a few typical fuel types is illustrated by Figure 5. Fuel No. 1 uses highly enriched uranium, highly diluted in a zirconium alloy. The cladding is also zirconium. Overall composition is 3% uranium, 97% zirconium. This material would be processed with the high enrichment Zircex headend at a pretreatment rate of 4 kg. of uranium/day. The tailend processing rate, which determines the charges, is 44 kg./day.

Fuel No. 2 is a molybdenum-uranium alloy, 27% enriched, clad in zirconium. After removal of stainless steel structural material with sulfuric acid, the zirconium cladding and the uranium-molybdenum alloy are dissolved by successive treatments with hydrofluoric acid and nitric acid. The dissolution and extraction rates are equal, both being 150 kg. of uranium/day.

Fuel No. 3 consists of low enriched UO_2 pellets in stainless steel tubular assemblies. The low-enriched Darex headend is used, at a rate of 1 ton/day. The tailend extraction rate is also 1 ton/day.

Some sample charge computations are shown in Figure 6. The batch size in the second column represents the reactor operator's judgment as to the optimum quantity processable at a given time after considering reactor loading schedules, use-charges on inventory, and the effect of shipment size on shipping charges. Following down the table on Fuel No. 1, the processing rate is determined as already outlined; this gives the number of processing days to which is added the turnaround time to give total plant days. The processing charges are then indicated. It should be emphasized, of course, that the significant cost is not the cost figured on a $/kg. basis, but rather the cost determined on the basis of $/mwd of heat or electrical-energy-produced. This will be determined by the degree of burnup the designer obtains from the fuel elements as well as the value of any bred material which can be recovered from the processed fuel.

On this basis, charges for the reactors so far studied by the Commission appear to be in the range of 0.2 to 2 mills/kw.-hr.

These figures do not, however, include the further steps in the fuel cycle in which the nitrate products are converted to either UF_6 or plutonium metal. A 1% loss in going from irradiated fuel to final product has been assumed and charged. Use charges

during processing and storage are not included but will be written into each contract.

Up to now in this discussion of fuel processing, no mention has been made of two of the Commission's most important areas of effort. These are commonly referred to as the *volatility* approach, and the *pyrometallurgical-remote refabrication* approach.

Volatility processing (*2*) (*3*), like aqueous processing, is capable of obtaining high decontamination of nuclear material from fission products. The idea of using the volatility of UF_6 as a separation method first came to light in the days of the Manhattan Project. With the main interest centered on Pu recovery however, there seemed to be little applicability of the volatility methods, because PuF_6, though presumed to be volatile, was regarded as difficult if not impossible to prepare.

Present processes can be discussed logically in two parts: those directed only at highly enriched U recovery, and those intended for uranium and plutonium recovery. Figure 7 shows these two basic concepts. In the highly enriched case, the uranium alloy is contacted with fused sodium-zirconium fluorides through which is bubbled gaseous hydrogen fluoride. The fuel element reacts to form UF_4 and fluorides of the alloy and fission products. The fused salt mixture is now contacted with gaseous fluorine which oxidizes UF_4 to UF_6. The hexafluoride is quantitatively and almost selectively volatilized from the melt, most of the fission product and alloy fluorides being essentially nonvolatile. The gaseous UF_6 now can be fractionally distilled, or selectively adsorbed and desorbed on a heated bed of NaF, yielding a product of extreme purity.

The lower flowsheet illustrates the bromine trifluoride dissolution of pure uranium or high-uranium alloy materials. Bromine trifluoride, a powerful oxidizing agent, transforms uranium to UF_4, after which it is oxidized to UF_6, and treated as shown above. The plutonium, which is present as plutonium tetrafluoride, is nonvolatile and remains with the fission product residue. Recent experiments indicate excellent progress on the problem of developing an all-volatility process, that is, one capable of removing plutonium, as plutonium hexafluoride.

Corrosion and engineering problems are indeed significant, but it should be emphasized that these processes have now progressed to the pilot plant stage of development.

Furthermore, it would be fair to say that volatility processing, particularly with respect to some of the highly enriched zirconium fuels, is at a more advanced state of development than the corresponding aqueous headend technology.

With the increasing interest in the optimization of the over-all nuclear fuel cycle, attention has been given to the *pyrometallurgical remote refabrication* approach. This involves short-cooled processing of irradiated material at reactor sites. For those reactors using solid fuel elements, a complete fabrication facility is an integral part of the processing plant. It is therefore possible to completely recycle nuclear fuel at the reactor, with transportation involved only in outgoing shipment of wastes and incoming shipment of cold-fuel-make-up materials.

The usual reasons for processing have been (1) the restoration of reactivity by "sweetening" or removal of reactor poisons, (2) the need for concentration and perhaps recycle of bred material, and (3) where applicable, the need for restoration of structural integrity. The degree of decontamination sought always has been of the order of one million times greater than that required for these purposes due to the need for direct fabrication. By fabricating fuel elements remotely, pyroprocessing takes advantage of the much less stringent decontamination factors required merely for reactor operation.

Fuel elements which can be processed and fabricated remotely must be of simple design. At this stage of development, this means elements that are made by casting and which use sodium bonding. Examples include the fuels for the Sodium Reactor Experiment (SRE) and the Experimental Breeder Reactor (EBR-II.) The actual chemistry of pyroprocessing is relatively simple. Merely melting the fuel releases the inert gas fission products. This is especially significant in the case of xenon which is an important reactor poison in thermal reactors. Holding the uranium in the molten state for perhaps 15 min. permits the volatilization of the alkali and alkaline earth metals because of their high vapor pressure at the uranium melting point. The residual fission products fall into a fairly regular series according to their electropositivities.

By contacting the uranium-plutonium-fission product melt with fluoride or chloride salts, or with oxides or graphite, it is possible to convert the more electropositive fission products to a compound or salt form, thus obtaining a phase separation of these impurities. Contact with a well-chosen fused salt can, as before, cause an oxidation-reduction reaction which transfers the plutonium to the salt phase, or plutonium can be partitioned into molten magnesium, a procedure analogous to solvent extraction. Separation of the low electropositive elements is usually not attempted. Experiments indicate that their presence contributes to the radiation stability of uranium alloys, and they are not especially objectionable as thermal poisons in moderate concentrations.

The pros and cons of pyrometallurgical methods are many. Among the advantages the following can be listed:

1. They are uniquely suited to molten metal reactors which in some cases could not operate without continuous processing because of fission product build-up.

2. The processing plant is quite compact; 1 kg. of uranium metal occupies 1/20 liter compared with approximately 4 liters of solution associated with 1 kg. in aqueous processing. This volume reduction factor of 80 can lead to substantial savings in equipment and shielding costs.

3. A large portion of the fuel cycle is eliminated by keeping metal as metal throughout the entire processing-refabrication sequence.

4. Short cooling is permitted due to the insensitivity of reagents to radiation damage. Decay of U-237, which of itself necessitates 90 to 120 days' cooling of the reprocessed uranium if direct fabrication is to be used, is completely eliminated. Inventory charges on nuclear fuels can be kept to an absolute minimum in this way.

5. Waste materials are already highly concentrated and may be more readily contained than the aqueous wastes currently stored.

Disadvantages of pyroprocessing include the following:

1. Fuel elements must be simple, and designed carefully with respect to the limitations inherent in this kind of refabrication.

2. While plant sizes are miniscule relative to conventional aqueous plants, they have high capital costs in terms of their throughput. This factor could conceivably negate all the inherent advantages.

As in most of the facets of nuclear technology now under investigation, only actual construction and operating experience will be able to resolve these over-all economic questions.

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Condensed from a talk before the New York Metropolitan Section of American Nuclear Society, New York, May 20, 1957.

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U.S.I. CHEMICAL NEWS

June ★ A Series for Chemists and Executives of the Solvents and Chemical Consuming Industries ★ 1957

Variety of Plastics Helps New Pump Lick Corrosion

Except for its drive motor, a new pump designed for electroplating and chemical service is made entirely of plastics. Six distinct kinds of plastic materials are used in its various components.

The pump body is made of polyethylene, the impeller of Hypalon. The filter and filter chamber utilize polyvinyl chloride, Dynel and a phenolic, while the hose is of vinyl. The pump handles from 50 to 300 gallons per hour, and, the manufacturer says, filters out all particles larger than about 1 micron. The plastics are said to take in stride such materials as chromic, fluoboric and nitric acids, and the filter successfully handles solutions of ferric chloride, silver nitrate, iron and lead fluoborate and many others.

Test Detects Trace Ethanol

A simple procedure for detecting trace amounts of ethanol in liquids has been developed and reported in the literature. It is especially sensitive when used with liquids that are free from water.

The test first oxidizes ethanol to acetaldehyde and then permits detection of the latter by reaction with nitroprusside. As little as 3 micrograms of ethanol in one drop of a benzenethanol mixture can be easily detected. Presence of water in the test liquid results in hydration of some of the acetaldehyde and thereby decreases the sensitivity of the test.

One to three drops of the sample are placed in a micro test tube, and several centigrams of hot copper wire or cupric oxide are dropped into the tube. A disc of filter paper moistened with one drop of a freshly made reagent (consisting of equal volumes of 5% sodium nitroprusside solution and 20% aqueous morpholine solution) is placed over the top of the test tube. If ethanol is present, a deep to light blue stain appears on the paper almost at once.

Tank for Nuclear Reactor Fabricated Entirely of Zirconium Alloy

A new experimental nuclear power reactor utilizes a tank fabricated entirely of Zircaloy-2. The complex assembly illustrates how conventional fabricating techniques can be modified to permit the use of zirconium and its alloys.

Because zirconium is highly reactive at high temperatures, welds of the metal and its alloys must be shielded against air. This shielding was achieved with a water-cooled apparatus specially designed to fit the spherical and conical shapes of the welded surfaces. The apparatus also directed inert gas at and behind the torch.

Nat'l Distillers Changes Name To Reflect Growth of Activities In U. S. I. Chemical Division

Now National Distillers and Chemical Corporation; U.S.I. Head Made an Executive V.P.; Third of 1956 Profits from Chemicals

National Distillers Products Corporation has changed its name to National Distillers and Chemical Corporation.

The new corporate title reflects the substantial growth of the company's chemical operations, which last year contributed 34% of operating profits before interest, taxes and minority interest.

ATTENTION: Users of Taxfree And Specially Denatured Alcohol

Users of specially denatured and taxfree alcohols who are in the process of filling out forms for renewal of their basic and withdrawal permits should note that U.S.I.'s parent company has changed its name (see story, next column).

When you file your applications with the Assistant Regional Commissioner—Alcohol and Tobacco Tax Division, please be sure to use the new company name, U.S. Industrial Chemicals Co., Division of National Distillers and Chemical Corporation.

National entered the chemical field in 1950 when it built a sodium plant at Ashtabula, Ohio. This operation is now a part of the U. S. Industrial Chemicals Co. division, acquired by the parent company in 1951. Today, all chemical activities of the corporation are conducted through its U.S.I. division and its subsidiary, National Petro-Chemicals Corporation.

Elect New Officers

Coincident with the name change, John E. Bierwirth, president of the corporation, announced the promotion of a number of key executives. Among these were Dr. R. E. Hulse, Roy F. Coppedge and B. C. Ohlandt, who were elected executive vice presidents. Dr. Hulse is executive vice president in charge of the U.S.I. division, with responsibility for all

MORE

New Officers at National Distillers — U.S.I.

Dr. R. E. Hulse, new Executive V. P. of National Distillers and General Manager and V.P. of U.S.I. Division, directs Corporation's chemical operations. He joined National in 1949 as Director of Research and Development. William P. Marsh Jr., Assistant General Manager of U.S.I. Division and V.P. of National Distillers, has been named U.S.I. V.P. as well. Dr. Stuart Schott, with National since 1945, is new Research V.P. of U.S.I. Francis Olmsted heads the Development Department as a U.S.I. V.P. Alden R. Ludlow, Jr. joined company in 1934, has now been made U.S.I. Sales V.P. R. H. Cornwell was appointed U.S.I. V.P. of production, and is in charge of all U.S.I. and National Petro-Chemicals plants.

R. E. Hulse

W. P. Marsh, Jr.

S. Schott

F. Olmsted

A. R. Ludlow, Jr.

R. H. Cornwell

June ★ **U.S.I. CHEMICAL NEWS** ★ 1957

U.S.I. "Chemical News" Marks 25th Anniversary

Has Largest Circulation of Any Publication in Chemical Industry

With this issue, U.S.I. "Chemical News" rounds out 25 years of service to the chemical processing industry. Today, "Chemical News" is the most widely circulated medium of its kind in its field. It is regularly inserted in all leading U.S. chemical periodicals, and in addition has substantial distribution by mail. Combined circulation is over 320,000.

Attracts Many Inquiries

The high degree of interest in "Chemical News" is reflected both in inquiries and in readership ratings, and last year it brought thousands of inquiries about the products and services mentioned in its columns. And it consistently gets the highest advertising readership ratings in publications where it appears.

One reason for this sustained interest is that "Chemical News" does not confine its columns to information about products of U.S.I. Considerable space is devoted to items about products of other manufacturers, to research findings and to processing technology. In short, "news value" is the editorial criterion.

The Technical Developments column, a regular feature of page 2, describes new products and processes that range across the entire industry. Manufacturers who have something new to tell their prospects can take advantage of this column by writing the Editor.

SOLVENT NEWS

ALCOHOL PRICES RELEASED TO THE INDUSTRY FOR THIRD QUARTER

NEW LACQUER LOWERS OIL AMOUNTS

The first U.S.I. "blue sheet"—June, 1932. The name was later changed to "U.S.I. Chemical News" to reflect the expanding activities of the company.

Would You Like to Get "Chemical News" by Mail?

If you would like to make sure you see every issue of "Chemical News" or, if you keep a permanent file of them, as many readers do, ask to be put on the mailing list. Just write Editor, U.S.I. Chemical News, U.S. Industrial Chemicals Co., 99 Park Ave., N. Y. 16, N. Y.

New Polyethylene Squeeze Tube Keeps Original Shape

A new kind of squeeze tube has been developed. Made of polyethylene, it looks just like the familiar collapsible metal tube, but snaps back to its original shape after being squeezed to dispense part of its contents. In so doing, internal pressure is lowered and excess material at the mouth of the tube is sucked back inside. Advantages include less waste and no hardening or drying out of the tube contents.

CONTINUED ***Name Change***

chemical activities of the corporation.

Both Dr. Hulse and Mr. William P. Marsh Jr., U.S.I. Assistant General Manager and a Vice President of National Distillers, have been named Vice Presidents of the U.S.I. Division.

Four other executives were appointed U.S.I. vice presidents. They are: Robert H. Cornwell, who is in charge of production; Alden R. Ludlow, Jr., sales; Francis Olmsted, development; and Dr. Stuart Schott, research.

TECHNICAL DEVELOPMENTS

Information about manufacturers of these items may be obtained by writing U. S. I.

A non-corrosive leak detection paint is reputed to be effective in quickly spotting fissures to 0.001 in. dia. in assemblies, systems, tanks, etc. Ammonia works a color change at fissure. Paint is easily washed or wiped off. **No. 1240**

A tributyltin oxide to control microbiological slime in pulp and paper mill systems is reported highly successful under all pH conditions. Also non-corrosive, low in toxicity, and very economical. **No. 1241**

A spray-on sign cleaning "solute" is offered as compatible with water of 0-50 grain hardness, fast-acting, simple to rinse off, and harmless to steel, paint, and personnel. Cost claimed 1¢ per sq. ft. cleaned. **No. 1242**

Another radioactive carbon-14 compound joins available uniformly and specifically labelled radioactive amino acids. Uses are expected in the study of biological systems and amino acid formation and metabolism. **No. 1243**

Updated activated carbon solvent recovery systems are said to recover numerous solvents at a very economical cost. They also appear to increase both process efficiency and employee productivity. **No. 1244**

Detergent concentration is constantly controlled over a narrow range by a unique controller using neither vacuum tubes nor transistor circuitry. Equipment is reported priced for a wide market, with installation low in cost. **No. 1245**

A self-contained temperature stabilizer, quart size and factory sealed, has been designed to maintain a specified temperature within insulated shipping packages of up to 800 cu. in. It is reusable on recharge by purchaser. **No. 1246**

A 24-page brochure on lanolin reviews industrial origins of this wax, its composition, properties, U.S.P. grades, its cosmetic and pharmaceutical uses as emollient and emulsifier. Guide formulations are included. **No. 1247**

A selective flocculant for ore refiners is said to precipitate dissimilar particles suspended in aqueous mixtures when only 0.002% based on weight is added to the ore suspension as a cold water slurry. **No. 1248**

A new book on public relations for the atomic industry is being marketed. It discusses the atom as news, what the public wants to know about it, sources of information and techniques for approaching the public. **No. 1249**

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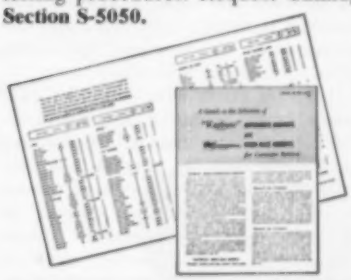


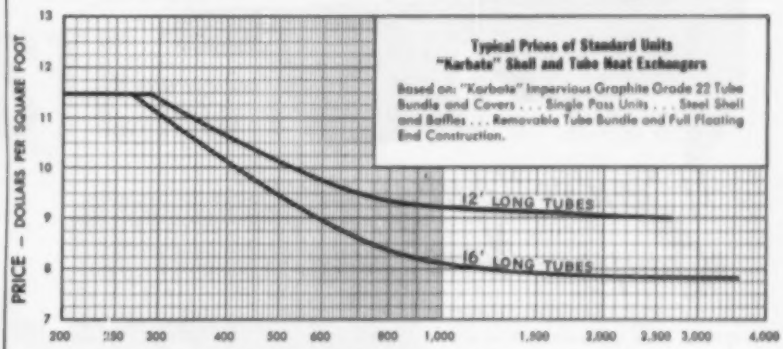
National Carbon Expands Carbon and Graphite Development Program

NIAGARA FALLS DEVELOPMENT LABORATORY

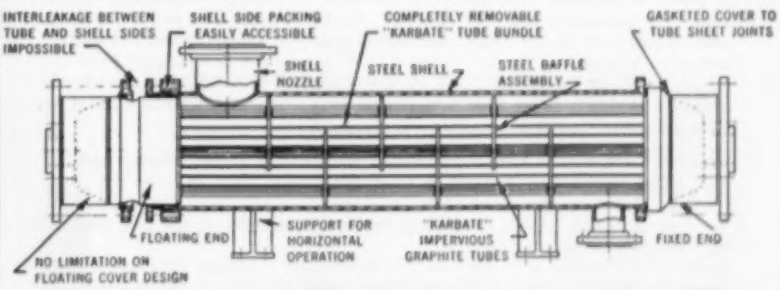
Maintaining its leadership in the broadening industrial use of carbon and graphite, National Carbon has expanded product development facilities at Niagara Falls, New York, to supplement new major research activities at Parma, Ohio. A large share of the expansion is devoted to development and evaluation of graphite anode materials for the electrolytic production of chlorine-caustic, chlorates, sodium and magnesium. The test room shown below contains miniature electrolytic diaphragm-type chlorine cells used in laboratory performance tests on "National" graphite anodes.

ELECTROLYTIC ANODE TEST ROOM

Quick Reference Chart Covers Prices of "KARBATE" Impervious Graphite Shell and Tube Heat Exchangers



New pricing charts on "Karbate" impervious graphite heat exchangers show their economy for all types of heat transfer involving corrosive fluids. Standard units assembled from stocked components, covering 16 shell sizes from 6" through 45" diameter and containing from 9 to 685 ⅞" I.D. impervious graphite tubes in 6, 9, 12, 14 and 16 ft. tube lengths, can be shipped in 3 to 5 weeks. Cut away view below demonstrates how sturdy, durable construction utilizes "Karbate" impervious graphite's corrosion resistance, immunity to thermal shock and freedom from metallic contamination in corrosive service. For price and product data, request **Catalog Section S-6800.**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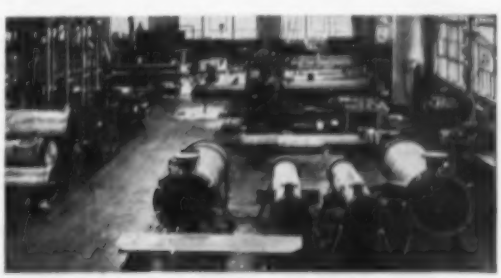
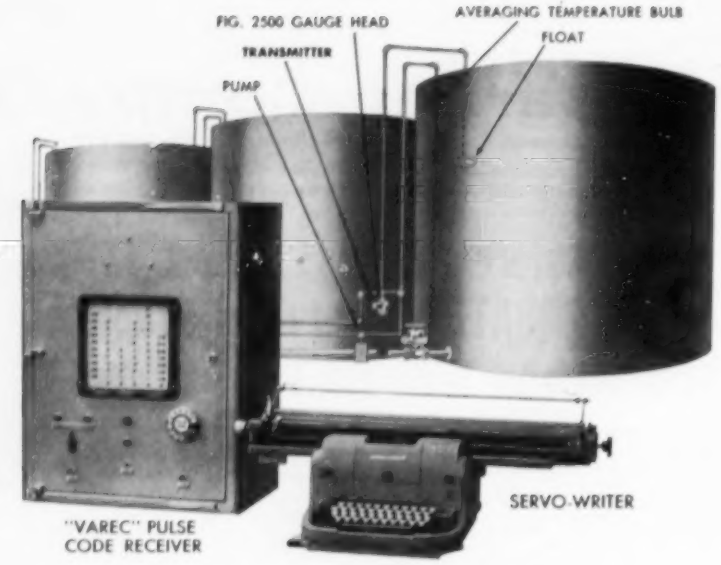
FIXED END
NO LIMITATION ON FLOATING COVER DESIGN

View at right shows assembly and test facilities producing "Karbate" shell and tube heat exchangers. Units have "Karbate" impervious graphite tube bundles and covers assembled in shells of steel or materials such as glass or rubber lined steel, "Haveg" phenolic resin, aluminum or impervious graphite.



NATIONAL TRADE MARK

The terms "Karbate" and "National", "N" and Shield Device are trade-marks of Union Carbide Corporation



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"Varec" PULSE CODE Telemetering can give you an accurate transmission system over unlimited distance for remote gauging of liquid level, temperature reading, and remote control of valves and pumps. A printed record can be provided by an electric typewriter.

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The pulse count system relies on transmitting, receiving and counting a number of pulses to represent intelligence. For example, to telemeter the number 10, ten pulses are transmitted and then "counted" by the receiver. The pulse count may send 10 pulses for 10, but due to variations in the power supply, receive and indicate only nine. Whereas, if "Varec" PULSE CODE lost a pulse in transmission for any reason, the signal would make no sense to the receiver. So it refuses to provide any indication, which is better than indicating an error. Same action would occur if an extra pulse were received.

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Marginal notes

Designing Process Plants

Project Engineering of Process Plants, H. F. Rase and M. H. Barrow, Wiley, New York, 692 p., $14.95.

A well-annotated and full illustrated description of the techniques used by the process plant designer, this book should find wide use as a guide to those who design and to those who aspire to be project engineers.

The book is divided into four parts corresponding to the main steps in the evolution of a process plant, beginning with plant location and ending with construction. Part I, titled "Major Steps in Plant Design," is 110 pages in length and covers plant location, preliminary design data, process engineering, flow diagrams, plans, scheduling, and design and drafting.

Part II consists of a 52-page section on business and legal procedure. The material is further subdivided into discussions of procurement operations, office procedure, and contractors.

Part III starts with a lengthy (207 pages) compilation of descriptive information on standard processing equipment such as vessels, heat exchangers, pumps, compressors, power drives, etc. A 20-page chapter on "Other Process Equipment" covers centrifuges, cooling towers, crushers and grinders, classifiers, crystallizers, evaporators, filters, heaters and furnaces, materials handling, mixing and mixing equipment.

A 78-page chapter on piping design stresses standard components and includes a tabulation of typical specifications. Typical forms and properties of thermal insulation are summarized in a 24-page chapter.

The chapter on process instruments (47 pages) describes typical types and includes a three-page table of instrument applications. Control systems are touched upon briefly. The remainder of the chapter deals with plant utilities (40 pages), foundations and buildings (46 pages), and plant safety (17 pages).

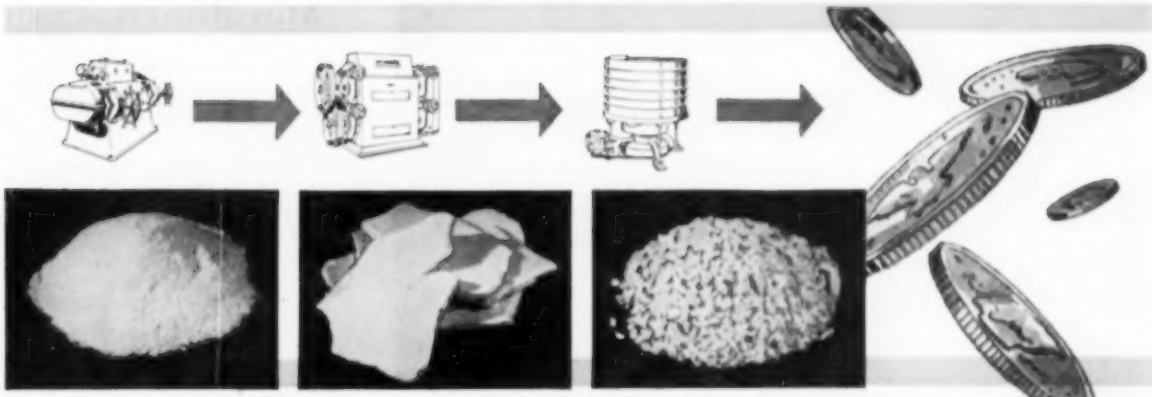
Part IV on construction occupies 16 pages.

For those who want a convenient guide to project engineering and a selective compilation of typical information, data, and specifications based on the authors' experience as project engineers, this book should fill a useful need.

Carbon Tet Safety

American Standard Maximum Acceptable Concentration of Carbon Tetra-

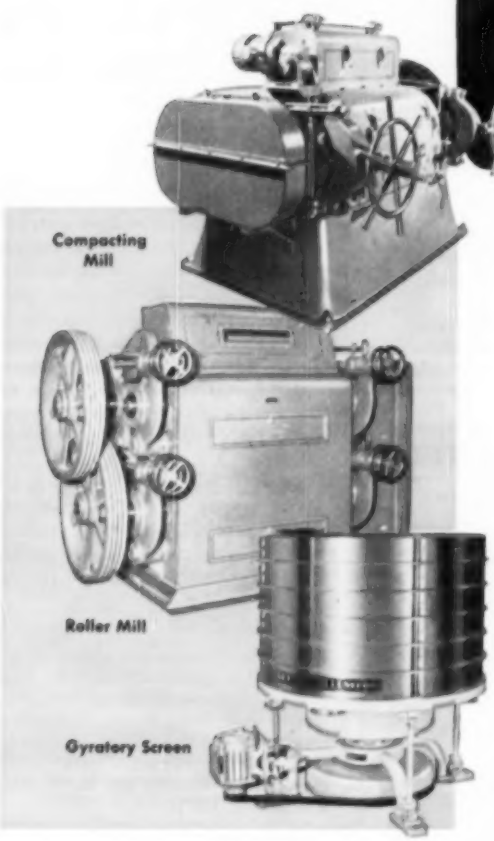
(Continued on page 28)



Converts WASTE into PROFIT

ALLIS-CHALMERS Compacting Process

it's mechanical
it's economical



You start with a pile of practically worthless material and wind up with a profit! Magic? Well, hardly – unless you want to call the mechanical efficiency of the Allis-Chalmers Process System magic.

How It Works

In a recent installation the conversion starts with an unusable, unacceptable minus 30 mesh chemical salt . . . fines created in the original process. An Allis-Chalmers compacting mill densifies these fines into flakes or slabs. Flakes are granulated in an Allis-Chalmers roller mill. Final separation is made in an Allis-Chalmers stainless steel gyratory screen. Result – 70 to 80% recovery of salable product. What's more – the resulting granules equal or surpass the natural product in every respect.

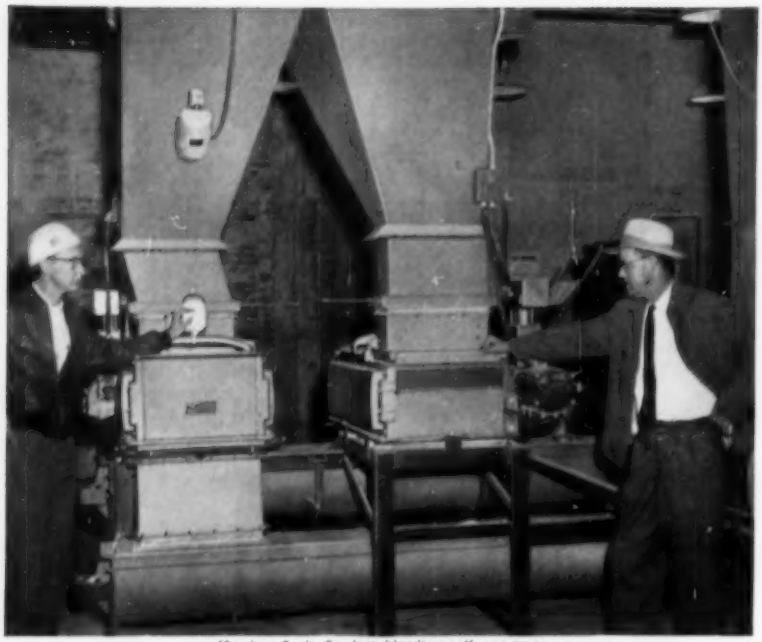
The entire system is mechanical; therefore, it's more economical than controlled crystal growth.

For More Information

Get the complete story from your A-C representative or write Allis-Chalmers, Industrial Equipment Division, Milwaukee 1, Wisconsin. Ask for Bulletin 25C6177J.

ALLIS-CHALMERS

A-5345



Merchen Scale Feeders blending salt and trace minerals at Carey Salt Co., Hutchinson, Kansas.

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offer continuous dry blending by weight

The Carey Salt Company produces salt blocks for cattle that contain a percent blend by weight of nutritional minerals. W&T Merchen Scale Feeders were selected for the blending operation.

If accurate blending of dry, free flowing materials is important to your production, Merchen Scale Feeders offer feed rates from 3 ounces to 3000 pounds per minute, always maintaining accuracy within 1% of the feed rate. The feeders compensate for changes in material density to maintain a constant feed by weight.

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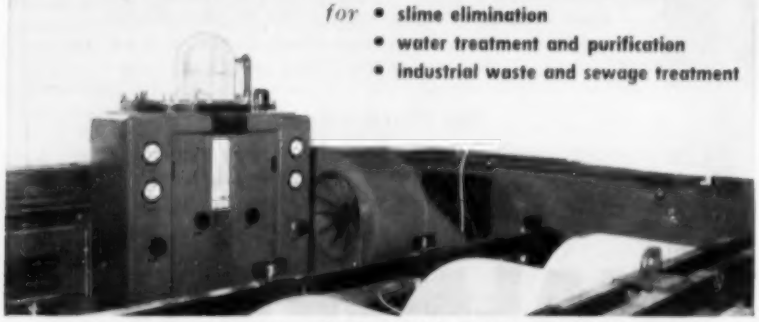

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CD-61

Marginal notes

(*Continued from page 26*)

chloride, Z37.17-1957, American Standards Association, 70 East Forty-Fifth Street, New York, fifty cents.

Purpose of the standard is to "prescribe the maximum acceptable concentration of carbon tetrachloride in the atmosphere of work places for guidance in design and operation so as to protect the health of workers." As in the case of other standards published by the American Standards Association, this brochure is considered to be a guide toward good hygiene and is not intended as a legal requirement.

Covered in detail are general, physical-chemical, and toxic properties of carbon tetrachloride, recommended acceptable concentration, and sampling procedures and analytical methods.

An exhaustive bibliography lists specific and general references.

W. H.

Low Temperature Proceedings

Proceedings of the 1956 Cryogenic Engineering Conference, Chemical Engineering Department, Univ. of Colo., Boulder, Colo., 368 p., $2.00.

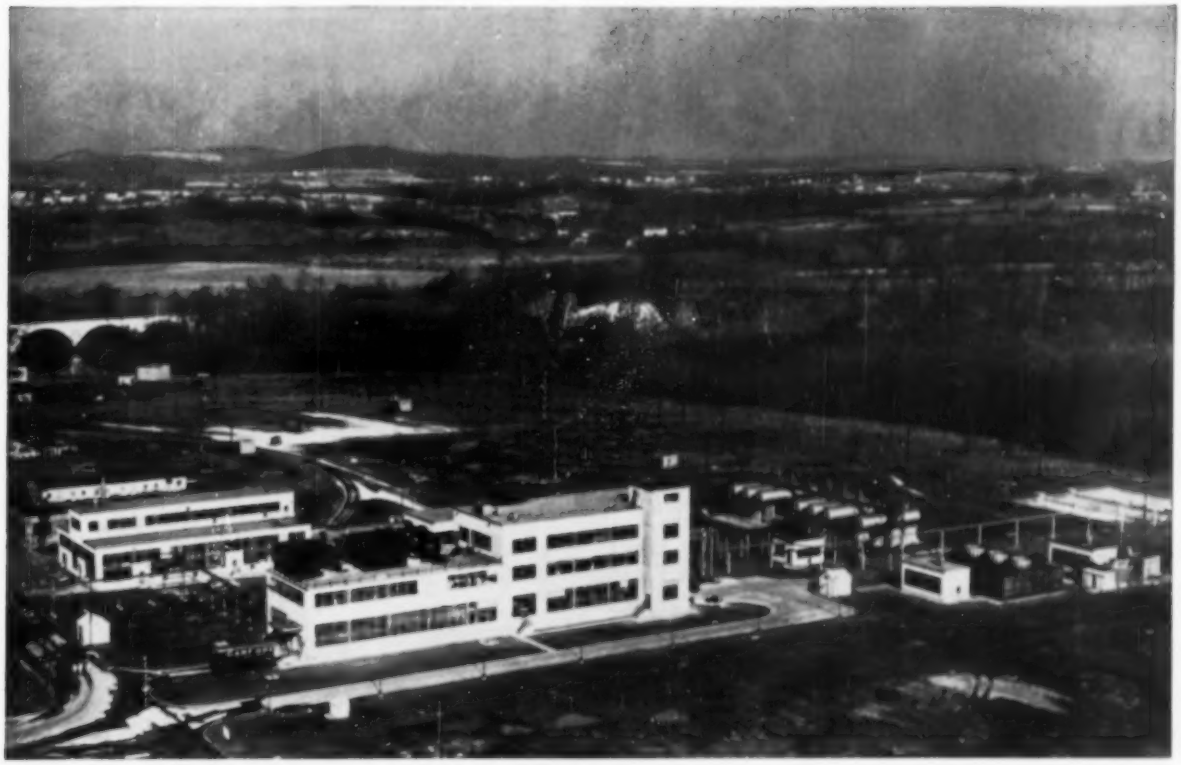
Contains summary or entire text of forty-nine papers presented at the conference. Subjects include: hydrogen liquefaction, catalysis of ortho-para-hydrogen, distillation of hydrogen isotopes, freeze-out purification, oxygen and hydrogen storage dewars, mechanical properties, thermal properties, magnetic properties, insulation properties of powders and foams, gas chromatography, design of airborne cryogenic equipment, refrigeration machines, expansion engines and impulse turbines, liquefied gas transfer, and bubble chambers.

Since most of these papers will not appear elsewhere in the literature, the Proceedings should be a valuable reference for future cryogenic engineering work.

All About Yeast

Yeast—Its Characteristics, Growth, and Function in Baked Products—a Symposium. Department of the Army, Research and Development Command—Quartermaster Food and Container Institute for the Armed Forces. Edited by C. S. McWilliams and M. S. Peterson (1957), 120 p.

This symposium, held at The Palmer House, Chicago, Illinois, June 22, 1955, covered the background and basic principles of active dry yeast, its function in baked products, including its effects on bread flavor, and also problems of production.



Polyvinyl chloride resin plant of Firestone Tire & Rubber Co., designed and constructed by Blaw-Knox engineers

Polyvinyl acetate plant designed and built by Blaw-Knox for National Starch Products Inc.—later doubled in capacity by Blaw-Knox

Vinyl chloride monomer and polymer plant built for Glenn L. Martin Company and subsequently expanded for U. S. Rubber Company

Blaw-Knox has been building vinyl resin plants for over 10 years

Blaw-Knox is a pioneer in the design, engineering, and construction of complete plants for the resins and plastics industry. Included are new installations and expansion of existing facilities for both polymer and copolymer production. This extensive experience and accumulated technical "know-how" is available to you. We invite you to discuss your plans with our engineers.

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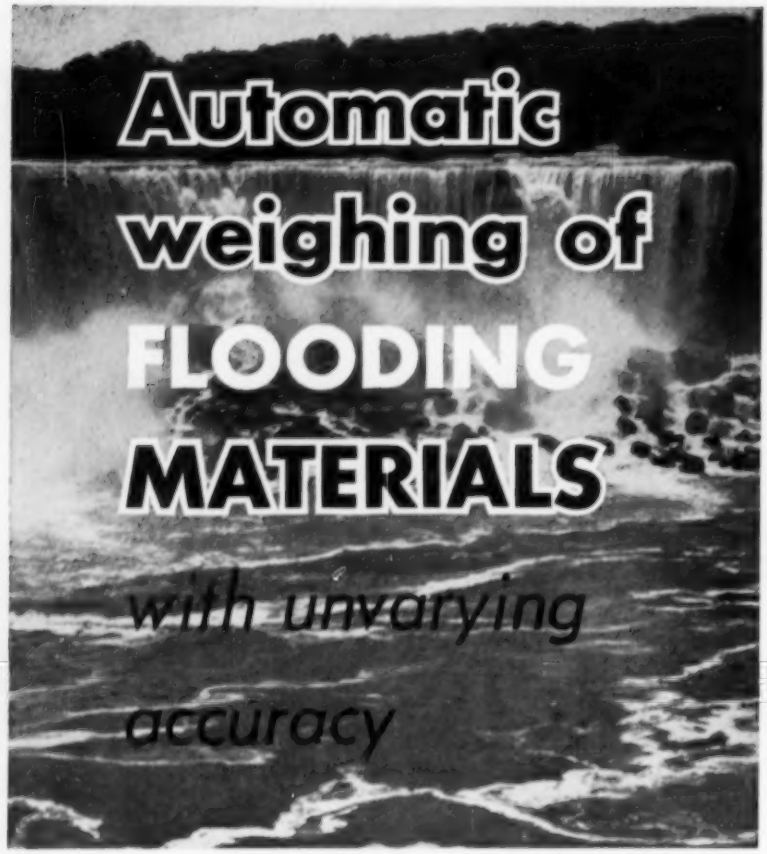

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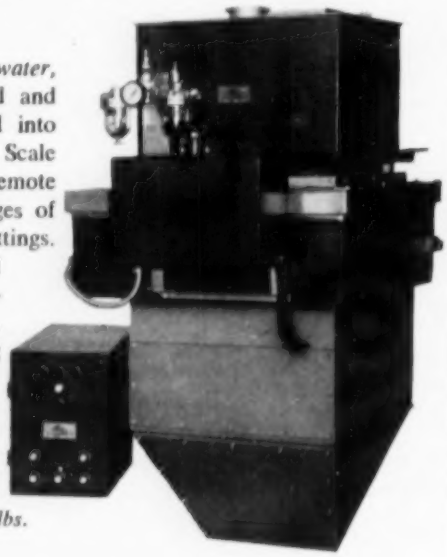

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About our authors

Alvin M. Weinberg, who writes on the Aircraft Reactor Experiment (ARE) at Oak Ridge, is Director of the Oak Ridge National Laboratory and has a long record as an outstanding nuclear scientist.

Another author on a major nuclear topic in this issue of *CEP* is **Edward L. Anderson,** Assistant Chief, Chemical Engineering, Division of Reactor Development, AEC, who is responsible for overall direction and coordination of the Commission's research and development in fuel reprocessing technology. His description of the conceptual multipurpose chemical processing plant is of widespread significance to the chemical industry, as was reported in the News Section of *CEP* last month (p. 64). The exact form that the plant will take, who will build it—government or private firm—and what will happen to the radioisotopes separated out by the processing are all factors of industry contemplation.

Frank E. Pavlis (Air Products, Inc.), writes an introduction to the subject theme of this month's Special Feature: Low Temperature Processing. Pavlis tells *CEP:* "When I entered the low temperature processing field in 1939, I found that the industry was divided into quite separate elements. Much of the low temperature equipment was fabricated in Germany or France and followed power plant prototypes and mechanical engineering viewpoints. The shuttle system of transportation between producer and consumer used up more capital than did the process equipment itself." One of the founders of Air Products, Inc. (in 1940), Pavlis plunged into the design and fabrication of small oxygen producing air separation plants. Now, 17 years later, Pavlis says he is personally concerned with technical, sales, and financial matters as his major activities.

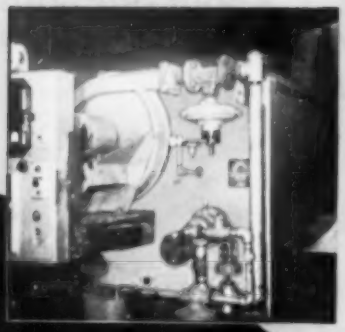
R. J. Corruccini is in charge of research on properties of materials at the Boulder, Colorado Cryogenics Engineering Laboratory of the National Bureau of Standards. In his presentation of those properties of materials at extremely low temperatures which

(Continued on page 32)

Anderson

Pavlis

Corruccini



For wide uses from nylon mold dipping bath to cooling exothermic catalytic reactor, use **Model FH fuel heated-bath type.** (May also have circulating pump and/or external salt cooler.) Available in duties from 10,000 to 10,000,000 Btu/hr

Beth-Tec systems are a molten salt mixture (duPont's HI-TEC) which melts at 280°F. The salt has NO vapor pressure, is non-toxic, non-corrosive, non-fouling, chemically stable and inexpensive.

We have the complete information on metals, heat transfer properties, fluid flow, piping and insulation to apply molten salt to your high temperature processing needs.

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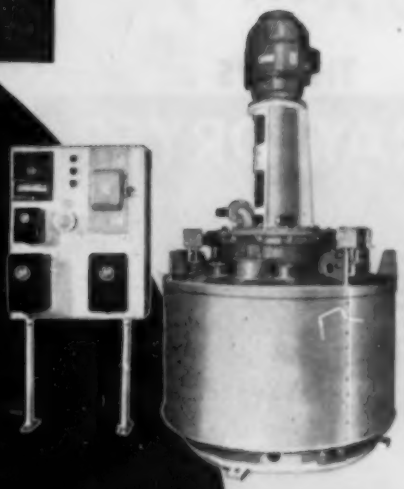
Your Logical Choice for High Temperature Heat Transfer (600°-1000°F).....



For small scale and laboratory operations—heating or cooling use **MODEL EH electrically heated, with circulating pump.** (May also have external salt cooler). Laboratory units available in standard designs for duties from 10,000 to 250,000 Btu/hr.

BETH-TEC SYSTEM

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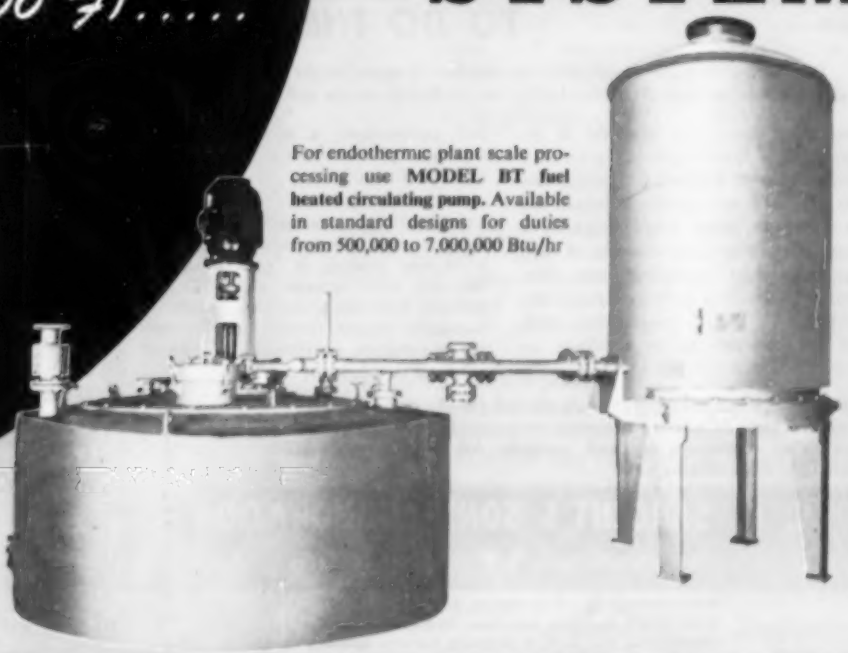
For endothermic plant scale processing use **MODEL BT fuel heated circulating pump.** Available in standard designs for duties from 500,000 to 7,000,000 Btu/hr



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TO DO THE JOB!

For wet powdered, sensitive or unstable materials that must be dried slowly and with utmost care

Sargent builds these dryers with any number of trays; single or multiple stacked; one or more deep; for highly varied drying speeds and material loads.

The dryer above, for example, is installed in a cotton-seed oil processing plant. Another SARGENT design, for wet powdered and unstable materials, has 40 trays, 10 high, double stacked, 2 trays deep. The entire interior of this dryer-evaporator (including trays, fan, housing, inlet vanes, baffles, exhaust ports, etc.) is of a special type stainless steel. Air splitters and baffles distribute an even air flow across every tray. Guaranteed performance: a minimum of 100 lbs. water removed from a 200 lb. charge in 8 hours at 60° C.

SARGENT dryers are designed with product protection paramount. Every dryer, every new product, is "proven out" in Sargent's own expertly staffed Drying Research Laboratory, for *your* protection. Unusually rugged construction, economy and dependable guaranteed performance are Sargent standards.

There's a SARGENT dryer to do the job for the process industries — **conveyor or tray; pole or tunnel; stationary or rotary. High speed or low, heavy capacity or light; continuous or batch methods. All Sargent-designed for the specific job. For more details, write**

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About our authors

(*Continued from page 30*)

will be of major value and interest to chemical engineers, Corruccini explains that he attempted not only to provide direct design data, but to endeavor to go into the "why" so as to enable the reader to extrapolate as necessary.

L. A. Wenzel is Associate Professor in the Department of Chemical Engineering at Lehigh University. A consultant in the field of low temperature for the past five years, he says: "One of the persistent problems has been in the design of distillation columns." This has led to the work reported on in this issue which Wenzel feels is representative of current engineering practice. He has tried to point out the large areas where the design engineer must rely on educated guesses and large safety factors. He hopes that this may aid in directing attention to the need for research in this area.

Norman C. Updegraff is head of process development for the Girdler Company. Girdler is experienced in the low temperature processing field as far back as 1929, when one of its subsidiaries, the Helium Company, undertook the separation of the eight per cent helium content from a natural gas stream at Thatcher, Colorado. Also present was 15 per cent carbon dioxide, the removal of which was also necessary to avoid freeze-ups in the low temperature equipment used for isolating the pure helium. Because of this, a new process was needed, and triethanolamine was tested with successful results. The process developed from its use came to be known as the Girbotol process. Norm was for several years with Du Pont before joining Girdler. After long service in the development and design of processes, he has more recently been engaged in sales engineering.

M. S. Peters is on the Chemical Engineering staff at the University of Illinois. His primary interests have to do with research in kinetics and mechanisms. He is presently studying aldehyde and nitrogen oxide reactions under a National Science Foundation grant. He worked at one time in the field of designing, construction, and operation of a plant for production of

(*Continued on page 34*)

Wenzel

Updegraff

Peters

This SWECO-built refinery addition helped an Indiana plant pull from behind to a front position in the race to upgrade gasoline.

High Octane Package Handled with Care

Like many refineries, the Mt. Vernon plant of the Indiana Farm Bureau Association was caught with its rating down when the latest high octane race started. That was before SWECO wrapped up a $1,500,000 refinery package that included a 3,000 BPSD platformer, a 2,100 BPSD unifiner, and a new steam generating plant with an hourly capacity of 120,000 lb. of high-pressure steam.

Off and running

The platformer-unifiner team went on stream in November, 1956, and has been in continuous operation ever since. This combination unit, built under license from Universal Oil Products Company, makes Mt. Vernon a front runner in today's race to upgrade gasoline.

In planning the steam generating plant, SWECO engineers decided to save time by specifying the equipment and letting bids for fabrication. But outsiders couldn't meet the cost estimates or contract, so SWECO built the pressure vessels in its Los Angeles plant. They were delivered three days ahead of schedule.

Problems in stride

Heavy spring washouts and a tight budget were just some of the problems the SWECO engineering and construction crews took in stride. Designing and building moderate-size refinery installations is their specialty.

This is the kind of service, the extra service SWECO clients in the process industries expect. Large or small, at home or abroad, it's the only kind they get . . . in the *engineering and construction* of refineries (SWECO *is licensed to build plants for practically all major refining processes)*, chemical plants and ore beneficiating mills . . . in the design and manufacture of *process equipment* such as heat exchangers, steam jet ejectors and distillation columns . . . in a full line of *vibrating screen separators*.

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at lower cost

There's an ACE hard rubber, rubber-lined, or plastic-lined valve for every corrosion application. Sizes from 2" to 24". Diaphragm, gate and check types. Free *Bulletin CE-52* lists chemicals that can be handled.

Take the guesswork out of CORROSION

No need for "trial and error" to find the right rubber or plastic chemical equipment. Consult American Hard Rubber Company first. Now eleven basic materials. Wide range of temperatures, pressures, strength. Backed by a century of experience. Write for facts today, or ask for name of Distributor.

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OR BIG PIPE LINES

ACE Rubber-Lined Steel . . . strength and pressures of steel plus chemical resistance of hard rubber. Excellent for alkalis, most inorganic acids, many organic acids, all salts, bleaches. Sizes 1¼" to 24" and up. *Bulletin CE-52.*

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Its made of a new rubber-plastic material that's tough, resilient, suitable for handling most acids and alkalis. 3-gal. size. Easy-pour, drip-proof spout. Also 1-qt. and 2-qt. dippers, hard rubber bottles, etc. Write for name of nearest dealer.

ACE processing equipment of rubber and plastics

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About our authors

(Continued from page 32)

pentaerythritol, the subject of his current *CEP* article.

Donald Kallman is a member of Babcock and Wilcox Company's Atomic Energy Division and is head of the Market Research Department. A chemical engineer from Yale, he received his nuclear education at AEC's Livermore, California laboratory.

M. F. Nagiev is a professor in the Petroleum Institute of the Academy of Sciences, Azerbaidjan SSR. His paper in this issue was produced in connection with the first International Congress on Catalysis held last Fall in Philadelphia.

Chemical engineer **Frank J. Soday,** active vice-president of Chemstrand, is experienced in both research and development and administration on the top level in the fields of plastics and synthetics. He was technical director of Copolymer Corporation (government synthetic rubber plant) during the war, and in charge of the group which developed the first successful civilian gas mask for the WPB. Active in A.I.Ch.E. local section work, Soday has also published extensively, not only in the chemical field, but also in the fields of archeology and anthropology.

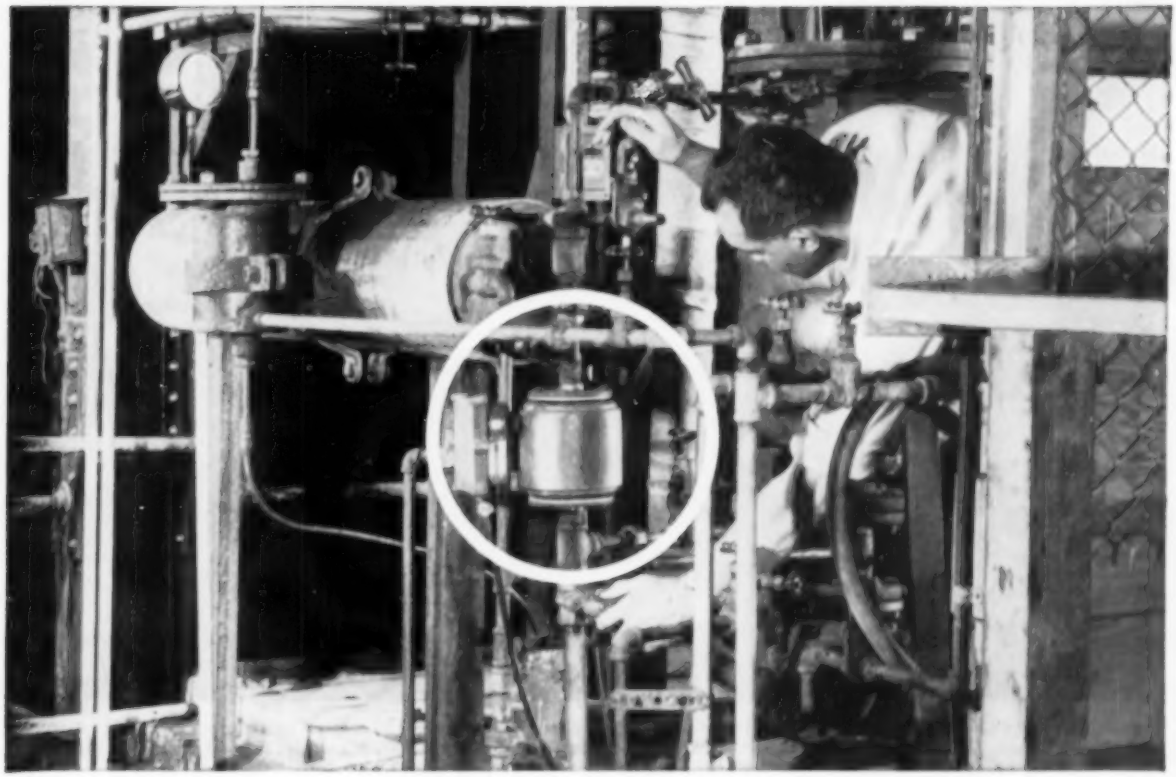
W. E. Gifford, experienced in helium and hydrogen liquefier design and analysis, is with the Advanced Research Division of Arthur D. Little. Trained in mechanical engineering and physics, he has worked with the AEC, where he originated a new concept for reactor safety devices. He now considers himself a "cryogenic engineer," dealing principally in problems of heat transfer and thermodynamics, and therefore somewhere in between the mechanical and chemical engineering fields.

Henry B. Lange, who has contributed this issue's article on the application of statistical methods to the correlation of laboratory and plant operations, is an associate chemical engineer in the Chemical Division of Merck & Company. With Merck six years, Lange was previously for two years with the Army Medical Center at Edgewood, Maryland, where he became interested in the mathematical aspects of chemical engineering.

Kallman

Soday

Gifford



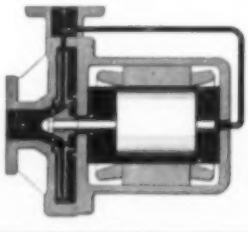
Chempump aids research program

handling sulfate liquor at St. Regis Paper Co.

Hot, black sulfate liquor is pumped into experimental digesters by this *Chempump* at St. Regis Paper Company's plant at Tacoma, Washington. Unlike conventional pumps, the *Chempump* is leakproof and virtually maintenance free . . . features that eliminate downtime and help speed the company's research program.

This *Chempump* can't leak, for it is a totally enclosed unit—no seals, no stuffing box, no packing. External lubrication is never required, as bearings are constantly lubricated by the pumped fluid itself. Extremely compact, the *Chempump* mounts right in the pipeline.

Where you require dependable, leakproof pumping, put a *Chempump* on the job. You'll profit considerably from its many advantages. For details concerning your specific application, write to Chempump Corporation, 1300 E. Mermaid Lane, Philadelphia 18, Pa. Engineering representatives in over 30 principal cities in the United States and Canada.



Chempump combines pump and motor in a single, leakproof unit. No shaft sealing device required.

U.L. approved. Available in a wide choice of materials and head-capacity ranges for handling fluids at temperatures to 1000 F. and pressures to 5000 psi.

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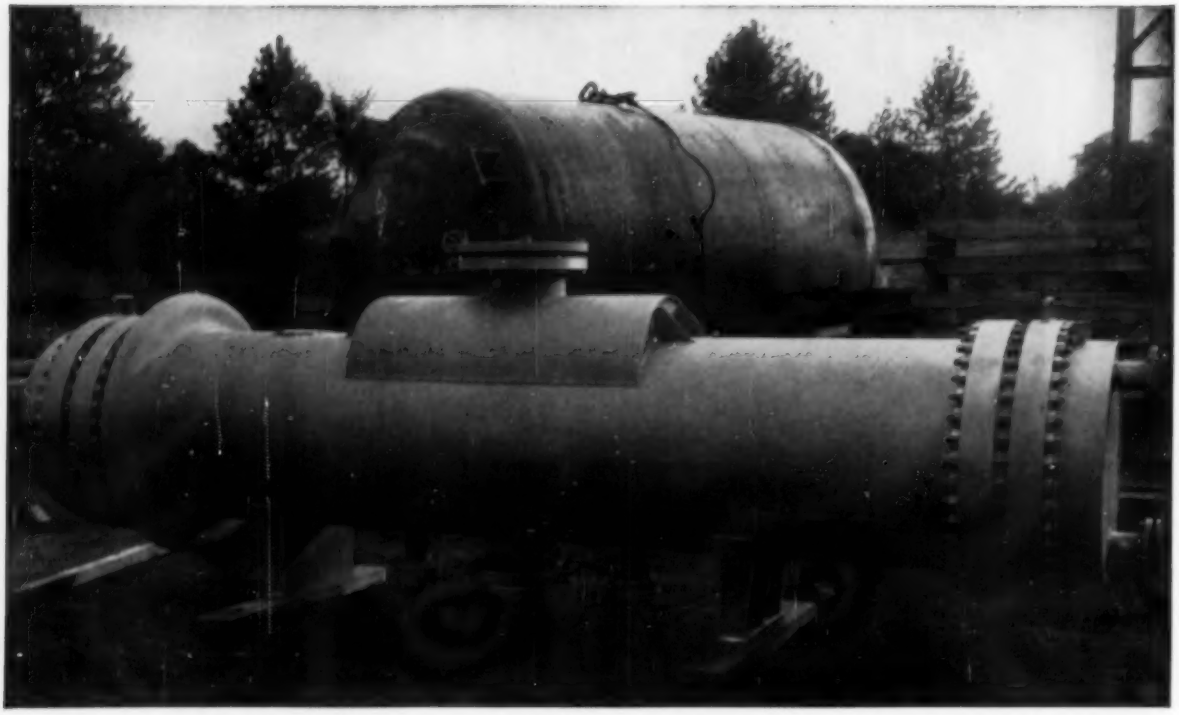
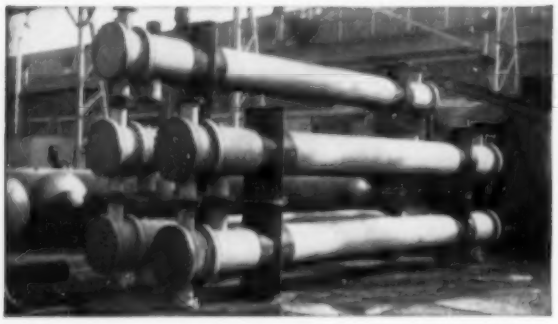
First in the field...process proved

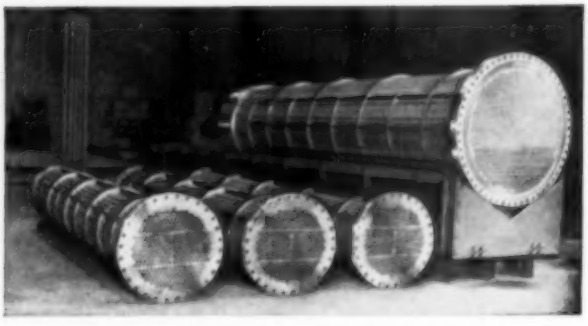


Inconel and stainless heat exchanger built for Barrett Division, Allied Chemical & Dye Corporation. Shell Diameter: 30". Tube Length: 12' 0". Tubes: 1" O.D. x 14 ga. Tube Sheet Thickness: 2". Materials: Inconel shell, tubes, tube sheets. Stainless steel heads, Type 316L.

Stainless steel plus nickel alloy equals corrosion-resistant heat exchanger by Downingtown



Aluminum bronze for these five coolers saved the customer 25% on equipment costs, assured corrosion resistance. Each fixed tube sheet unit is 20" in diameter x 20' tube length. Each has 282 aluminum bronze tubes ¾" O.D. x 12 ga. Centrifugally cast channels. Design pressure: 150 p.s.i. on both shell and tube sides.



Stainless steel Type 304 is the material for these four tube bundles. The large one fits a 37" shell, has 1225 stainless tubes, ¾" O.D. x 14'0" long. Tube sheet: 2⅞" thick. Baffles: ⅛" thick. The other three bundles are 22" in diameter; each contains 352 tubes ¾" O.D. x 16 ga. x 12'0" long. Tube sheets: 1¾" thick. Baffles: ¼" thick. All stainless steel.

Corrosion-resistant materials a heat exchanger specialty at Downingtown

We have the engineering, welding and fabricating experience to turn out your corrosion-resistant exchangers in the materials you specify: stainless, nickel, nickel alloy, aluminum bronze, carbon and many others. Our design recommendations often save money. Send for Bulletin HE. Your engineers will find it useful.

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CONTAINERS AND PRESSURE VESSELS FOR GASES, LIQUIDS AND SOLIDS

BORON COMPOUNDS AND THE CHEMICAL INDUSTRY

The big research push today is in new materials oriented toward what is romantically called the "jet age." Much of the work is being done in inorganic chemistry, a field that is still incompletely explored and which more and more shows indications of important new horizons ahead.

Foremost both in the public eye and in the eyes of scientists and engineers are what are called "exotic" fuels designed for rockets, guided missiles, and supersonic planes. These are made chiefly from compounds of boron and lithium, with the main emphasis on boron. The compounds being made and studied are comparatively new and therefore extremely expensive. As a result, most of the work on these fuels is being sponsored by the Armed Forces. Looking into the far future, however, it is not impossible that some of the new materials may become cheap enough to be used in commercial airplanes or even in new types of automobile engines, either directly or as additives for gasoline.

Boron Compounds

Borax production is around 900,000 pounds yearly, which is three times the output of only ten years ago.

While the exotic boron high energy fuels are commanding most of the interest at present and will probably be the first of the new boron compounds to go into large production because of plants being built under military auspices, other extremely interesting new derivatives are being aggressively studied.

Possible important new areas are in glass fibers, in new metal alloys, and in entirely new plastics, especially in combination with phosphorus. Since boron stops neutrons from a nuclear reactor and is used in control rods, it has been suggested that some of the new boron plastics, still in embryo stages, might be used as a lightweight shield in an atomic powered airplane. Besides the study of boron and phosphorus compounds, combinations of boron with sulfur, fluorine, and other elements, including organic materials, are being explored.

The work on fuels, while widely discussed in generalities, has been kept under security wraps as far as details go until lately. Fuel materials are produced in one method by reacting lithium hydride with boron trifluoride to yield diborane and a series of other boron derivatives including pentaborane and decaborane. Diborane produces as much as 32,000 Btu per pound, the pentaborane and tetraborane somewhat less—30,000 Btu per pound. Another starting material for fuels is borane trichloride, which now can be made by a new process adaptable to large scale production.

It is interesting to note that this whole new field, with its startling long range possibilities, is not the province of the wellknown giant chemical companies which took the lead and more or less dominated the organic field of coal tar and petroleum chemistry responsible for most of the growth of the industry over the past generation.

The only large company in the boron fuel field is Olin Mathieson Chemical Corp. Olin is now building a $36 million plant at Model City, N. Y., to make the new fuels for the Air Force. Callery Chemical Co. is building a $38 million plant at Muscogee, Okla. for the Navy. Both plants will make fuels derived from boron, lithium, and fluorine. Callery is owned 75 per cent by a comparatively small firm, Mine Safety Appliances, and 25 per cent by large Gulf Oil Co.

Olin has never been in the lithium or boron business and has no reserves of raw materials, but became interested first because of its production of hydrazine (which has possibilities as a rocket fuel), and then through its acquisition of holdings in two small pioneering rocket motor firms. It acquires its raw materials for its fuels from others.

But probably the most important research work, outside of universities and research institutes which have government contracts, is being done in the laboratories of those firms that have a direct interest in boron and lithium.

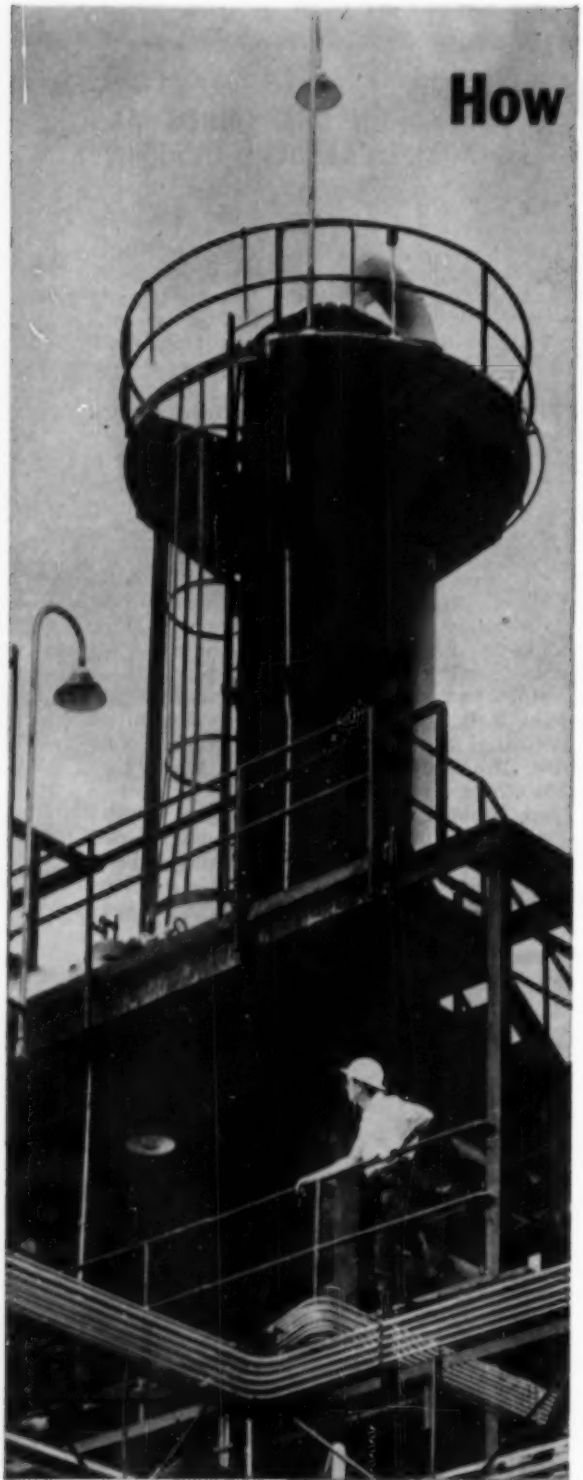
Firstest with the Mostest

With the commissioning of nearly $75 million in new plants for the Armed Forces, the business of exotic fuels, after years of test tube work and secrecy, now seems to be really on the road. It should stimulate commercial developments by the firms basically in the business, who are also receiving contracts for raw materials for the new fuels.

Rated as the largest owner of borax ore reserves in this country is U. S. Borax & Chemical Corp., which is controlled by the British Borax (Holdings) Ltd. U. S. Borax is preparing for the coming increasing importance of boron by spending $20 million on modernization of its mining facilities.

American Potash & Chemical Corp., Searles Lake, Calif., is rated as the second largest borax producer. It is also an important producer of lithium and has been conducting aggressive research into new compounds in both fields.

Next in holdings of ore is Stauffer Chemical Co., which got into boron chemicals partly because of this and partly because of its already solid accomplishments in the field of metal chlorides and fluorides. Stauffer is expected to be a major supplier of raw materials to Olin and perhaps to Callery and is now engaged in expanding its plant capacity to make fuel raw materials by a new process.



How the whole stainless family works to increase chemical processing profits

Because stainless is actually a large family of metals, it is important to choose the right one for best results. If corrosion problems exist along with high temperatures, for example, it would be well to discuss with your Crucible representative the possibility of using a stabilized grade of Rezistal stainless like type 318, 321, or 347. Again, although Rezistal type 304 is used extensively in heat exchangers for processes where organic acids, esters, and aldehydes are handled, type 316 may sometimes be a better choice. If extremely high temperatures and pressures are required, as in hydrogenation of high sulfur coal, type 446 might be considered for its excellent resistance to sulfidation.

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Crucible maintains a "Customer's Corrosion Laboratory" in which metallurgists and chemical engineers cooperate to study actual corrosion problems encountered in plants throughout the country. They are investigating, among other things, the effects of different joint conditions, various types of stainless, and the effects of highly corrosive media. Very possibly they have the answers to the problems you are faced with.

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CEP

opinion and comment

ERA OF SOURCES

The sources of information important to chemical engineers are today varied and dispersed. In many of the exciting frontier areas chemical engineers are of course leaders or major participants. Yet, it should not be overlooked that in some of these fields, information significant to processing is being developed by others who, unless care is taken, may not see the need for undelayed transmission of certain findings to the members of this profession.

Because of defense interests, considerable strides are being taken which entail both the practical and fundamental, in those fields having to do with properties of matter in both ultra high and ultra low (sub-earth) regions of temperature, in applications where fluids are caused to flow past surfaces at higher velocities than one normally considers possible, where combustion reactions are being analyzed in slow-motion and with such acuity as to permit stepwise tracing of life cycles of reaction products, and the exploration of reaction-stability effects of by-product sound. In such fields, heat is being generated at higher rates, transferred at higher rates. Equipment is often too thin, too light to withstand the conditions it does withstand because of the periods involved. Conventionally-excited molecules, impelled into new dance rhythms by fission-radiations, deliver better efficiencies and, sometimes, new products. "Bridge" hydrogens, which connect pairs of boron atoms, impart energies to combustion reactions which can send our planes further, give promise of the creation of exciting new compound possibilities including an inorganic plastic. New compoundings of materials appearing to withstand corrosion as good as the corresponding old offer hope for relief from critical tie-ups when our defense needs divert the customaries into unavailable channels. Electronic descendents of the abacus are being harnessed into what will provide the methods and experience that may revolutionize our processes with a profound effect on man's standard of living. Control systems for our most complex planes and elusive missiles are yielding simplified interpretations applicable to our processes.

Further, in areas less immediately related to military considerations, forces counter to the creativity of individuals when they group together as committees are being ferreted out into the open where effective countermeasures are being devised and taught. Decision-making is being given new scientific and mathematical assistance, and advances are being made in effecting decisions once they are made.

It would seem that the chemical engineer faces an era profound in its potential for the demonstration of his abilities. It would also seem that with so much going on in so many places, an open mind, a trained alertness, and a roving eye would be good equipment for dealing with this kind of situation.

—JBM

Recommended reading for CHEMICAL ENGINEERS

In the pages of this Painting Manual are data every maintenance engineer will want to have when faced with problems involving protective coatings.

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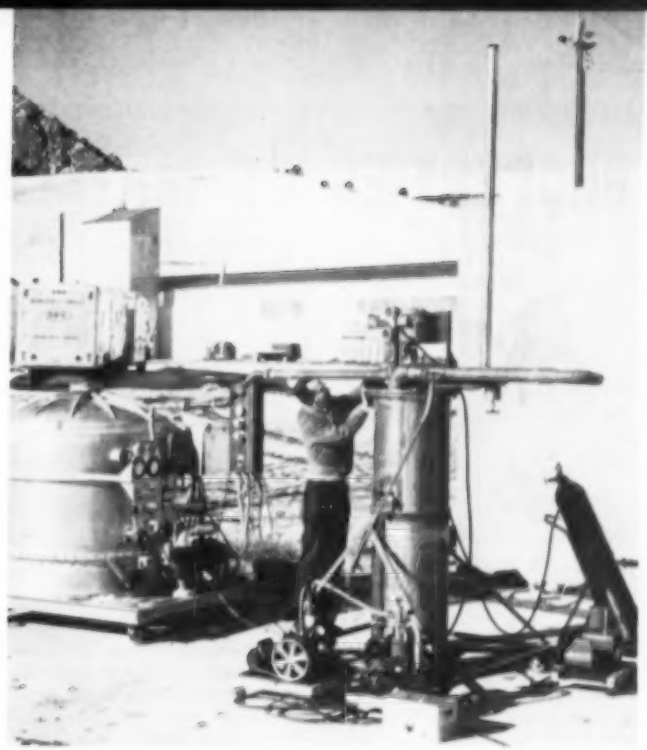
TO FURTHER YOUR INTEREST IN LOW TEMPERATURE PROCESSING

The 1957 Cryogenic Engineering Conference will be held August 19-21 at Boulder, Colorado. For further information, see listing under Future Meetings, page 90 of this issue. Also, another symposium on the basics of low temperature processing, plus a symposium on low temperature air plant safety, will be featured at the September Baltimore meeting (see page 86).



A 500-liter experimental Dewar for liquid hydrogen (left) and liquid hydrogen pump (right) at the Boulder, Colorado, Cryogenic Engineering Laboratory of the National Bureau of Standards.

THE CHEMICAL ENGINEER IN GENERATION AND USE OF LOW TEMPERATURES

The chemical engineer should be more interested in the low temperature properties of matter, and through this interest can make a unique contribution to modern technology by an increased participation in the effort to utilize these properties for new and better purposes.

Frank E. Pavlis | Air Products, Inc., Allentown, Pennsylvania

The industrial low temperature range starts with the temperature of liquid helium and rises for over 350° F. to a level of −100° F., or approximately 200° K., which may be regarded as the top of the low temperature range. This is about equal to the lowest natural temperature which is known to occur on the surface of the earth. Any temperature less than this must be attained by engineering methods.

If we arbitrarily select −100° F. as a terminal temperature and list the materials that have normal boiling points at lower temperatures, we will include the rare gases—helium, neon, argon, krypton, and xenon; some of the other constituents of air such as oxygen, nitrogen, and hydrogen; the halogen fluorine and some of its compounds; the compound nitrous oxide; and the light hydrocarbons—methane, ethylene, acetylene, and carbon monoxide. This list includes many of the most basic material building blocks that the chemical engineer utilizes in this chemical age. By low temperature engineering methods, these substances can be separated from various mixtures and can be purified to a high degree. They can be compressed, transported, and stored in liquid form; and they can be vaporized and heated at various pressure levels for industrial purposes.

Low temperature phenomena may be studied from the standpoint of low temperature chemistry, physics, or engineering. Chemical reactions and the associated thermochemistry at low temperatures have been inadequately explored. What do we know, for instance, about the oxidation of unsaturated hydrocarbons at low temperatures, or of the chemistry of free radicals? When we have a better understanding of low temperature chemistry, we will create more opportunities for low temperature chemical engineering.

The chemical engineer may be expected to contribute to the variation in the methods of obtaining and utilizing low temperature refrigeration. His main concern, however, will be with low temperature processing, where the broad principles of unit operations and thermodynamics will be utilized for a variety of useful purposes.

Low temperature processing includes the separation and purification of one or more components from fluid mixtures as well as changes in phase, pressure, and temperature. Low temperature processes include distillation, absorption, and adsorption. Changes in phase involve the formation of solids, liquids, and gases; changes in pressure involve compression and expansion; and changes in temperature involve sensible as well as latent heat effects.

Our military program during World War II and our subsequent national defense program have been responsible for the involvement of a large number of chemical engineers in the problems of low temperature technology. During World War II, considerable effort was directed to the production of oxygen from air under military conditions. In the postwar period chemical engineering attention has been directed to a variety of new low temperature problems, including those related to atomic energy, guided and ballistic missiles, high altitude aviation, and earth satellites.

PROPERTIES OF MATERIALS AT LOW TEMPERATURES

(PART I)

This review summarizes the knowledge acquired from work at the Boulder Laboratory on low-temperature data, organized and interpreted in the light of theory, and shows how useful estimation procedures may sometimes be derived from theory to fill gaps in the available data. Parts 2 and 3 will follow in the July and August issues.

R. J. Corruccini

Cryogenic Engineering Laboratory
National Bureau of Standards
Boulder, Colorado

Since the first attainment of very low temperatures around the turn of the century, physicists have found this region to be a fruitful source of unusual effects that manifest themselves only when the thermal excitations due to temperature are reduced to low values. Superconductivity and the superfluidity of helium are probably the most striking of these, but the transport of electricity and heat in solids, paramagnetism, and the heat capacities of solids pose difficult problems and continue to hold the attention of both experimentalists and theoreticians. To the engineer, these effects as well as the substances chosen to display them may appear exotic. Nevertheless some of them are sources of useful generalizations which may be applied to the prediction of the properties of engineering materials and which are given a special value by the scarcity of low-temperature experimental data on such materials.

The fields to be considered here are (1) heat capacities, (2) thermal expansion, (3) thermal conductivities, (4) thermal insulations, and (5) mechanical properties. The emphasis will be on materials of construction and, consequently, only solid properties will be considered. However, some of the conclusions in the first three sections will be applicable to process chemicals in the solid state. The author has freely used cgs. or British units according to whichever were predominant in the source literature.

An 840-liter air transportable dewar for liquid hydrogen developed by the Cryogenic Engineering Laboratory, Boulder, Colorado.

Heat Capacities

There is a wealth of heat-capacity data (*1, 2, 3*) on elements and simple compounds due to the usefulness of such data on chemical thermodynamics and in elucidation of atomic, molecular, and crystalline structure. The field of chemical thermodynamics, that is, the thermodynamic treatment of chemical equilibria, will be excluded arbitrarily from this review since it is extensive and is covered by numerous textbooks and compilations, and the discussion will be limited to the heat capacities of materials of construction such as might be required for heat-balance calculations.

A heat-capacity curve of the general shape shown in Figure 1 is characteristic of simple relatively isotropic crystalline solids. The broad features consisting of a high-temperature limit, a rapid decrease setting in as the temperature is lowered, and a final approach to zero at the absolute zero of temperature are characteristic of a quantum oscillator. For N such oscillators acting independently, where N is Avogadro's number, the atomic heat capacity is

$$C_v = 3R\left(\frac{\theta_E}{T}\right)^2 \frac{e^{\theta_E/T}}{(e^{\theta_E/T}-1)^2} = 3RE\left(\frac{\theta_E}{T}\right) \qquad (1)$$

where θ_E is a constant of the oscillator, R is the universal gas constant, and $E(\theta_E/T)$ is the Einstein function as defined by the equation.

The Einstein function shows the desired general temperature variation, and the factor $3R$ in Equation (1), being the limit approached at high temperatures where $E(\theta_E/T)$ approaches unity, correctly approximates the Dulong and Petit universal heat capacity of about 6 cal./(g. atom)(°K.). Nevertheless the Einstein function does not fit in detail actual heat capacities, the reason being that a solid is effectively a large number of coupled Einsteinian oscillators with various θ values, i.e., frequencies, the distribution depending on the lattice type and the interatomic forces. The accurate derivation of this distribution is laborious (*4*), but fortunately the specific heat is relatively insensitive to the form of the distribution, and the simple parabolic distribution assumed by Debye—although now known to be far from representative—nevertheless results in a satisfactory representation for engineering purposes of the specific heat data on most monatomic solids. This distribution results in the Debye function, $D(\theta_D/T)$, defined by

$$C_v = 9R\left(\frac{T}{\theta_D}\right)^3 \int_0^{\theta_D/T} \frac{x^4 e^x}{(e^x-1)^2}\,dx = 3RD\left(\frac{\theta_D}{T}\right) \qquad (2)$$

The Debye function, like any other based on summation of Einstein functions, shows the same general shape as the Einstein function including the monotonic decrease with falling temperature. Tables of $3RE(\theta_E/T)$ and $3RD(\theta_D/T)$ and the corresponding internal energy functions

$$U - U_o = 3R\int_0^T E(\theta_E/T)dT \text{ and } U - U_o = 3R\int_0^T D(\theta_D/T)dT$$

are given by Landolt-Bornstein (*5*). The most extensive tables of Debye functions for C_v and $U - U_0$ are by Beattie (*6*). The graphical form in which these functions are presented in Figure 1 is suitable for approximate calculations.

Equation (*2*) like (*1*) refers to the atomic heat capacity of an isotropic monatomic solid. It does not provide a good fit for highly anisotropic solids such as graphite (*7*).

COMPOUNDS AND ALLOYS

The more complicated situation in compounds and alloys can now be considered. Near room temperature the specific heat of a compound or alloy can be approximated quite well by linear combination of the specific heats of the constituent elements (the Kopp-Joule rule). This is because the temperature is sufficiently high that all modes of lattice vibration are fully excited (except for a few hard substances of low atomic weight, e.g., diamond, BeO, B_2O_3) and the gram atomic heat capacity is about the same for all the constituent elements (the Dulong and Petit value).

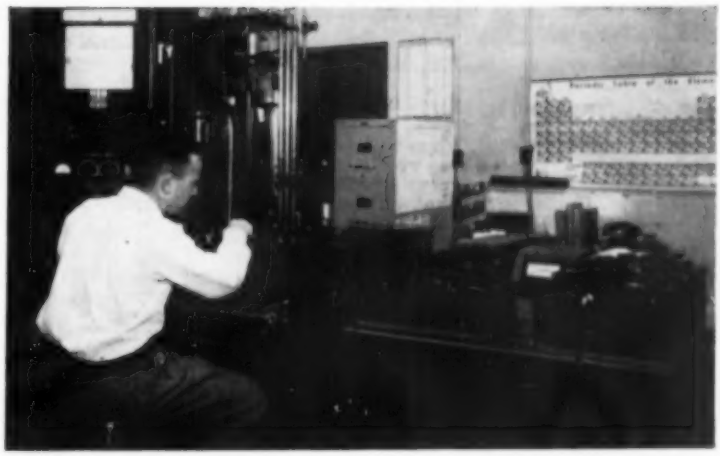
This procedure is not proper at low temperatures because there the specific heat is determined by the arrangement and bonding of the lattice, and for a compound this bears no relation to the lattice characteristics of the component elements as is seen at once by comparing the solid properties of an alkali halide with the alkali metal and the halogen as separate entities. Nevertheless the Debye function is found to represent simple compounds which form lattices with only one type of bonding (such as alkali halides, other binary salts, and some oxides), the θ_D value, however, bearing no relation to the θ_D values of the constituent elements. To comply with the Kopp-Joule law at higher temperatures, it is now necessary to multiply $D(\theta_D/T)$ by $3Rn$ for an n-atomic molecule to obtain the molar heat capacity.

Table 1 lists values of θ_D for a number of solids that can be represented reasonably well by the Debye function. For many of these, θ_D varies by 10% or more according to the temperature range being fitted. The values in the table are selected to favor the region, 100 to 300° K. The manner in which θ_D can vary with temperature is thoroughly discussed by Blackman (*4*).

Compounds containing groups or radicals which retain their unity in the lattice, or compounds (usually organic) which form molecular crystals often have heat capacities that rise continuously to the melting point without reaching a plateau and hence are not well represented by a single Debye function. Such heat capacities can be represented as a sum of two kinds of contributions, one a Debye term which approximates the effect of lattice vibrations involving the molecules or groups as units, and the other an appropriate number of Einstein functions, each representing an internal mode of vibration in the molecule or group. The θ_E values for the latter can be assumed to be given by the resonance frequencies, ν_i, exhibited by the molecules in Raman or infrared spectra ($[\theta_E]_i = h\nu_i/k$ where h is Planck's constant and k is the Boltzmann constant), the frequencies being to a first approximation unaffected by temperature or the state of aggregation of the molecules.

A classic application along these lines is the calculation by Lord, Ahlberg, and Andrews (*8*) of the heat capacity of solid benzene. A similar technique may be applicable to plastics. (Indeed all real specific heat curves, except in the vicinity of maxima or discontinuities due to special causes, can apparently be represented empirically by a sum of a small number of suitably chosen Debye and Einstein functions.) However, the plastics are distinguished by having elastic constants that are strongly temperature dependent (see section on mechanical properties), and as a result it would be expected that θ_D for the lattice vibrations would increase strongly with decreasing temperature.

Another class of solids that fails to fit the Debye functions is the glasses. Low-temperature data are available for only a few that are of commercial importance including fused silica (*9*) and several elastomers (*10*). These substances have in common a "glass" transition at which the specific heat rises nearly discontinuously with rising temperature. This type of transition is attributed to the release of modes of motion involving only limited portions of the molecular structure. The location and shape of the transition depend on the rate at which it is caused to take place, and there may be accom-



Cryogenic Engineering Laboratory for measurement of thermal conductivity.

Fig. 1. Heat capacity curve typical of simple relatively isotropic crystalline solids.

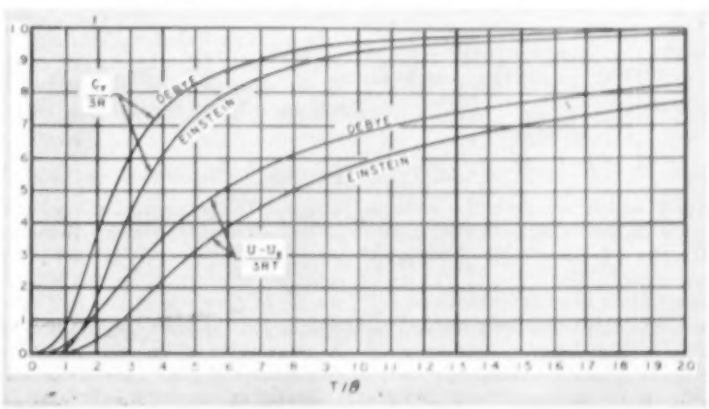


Table 1.—Debye and Grüneisen Constants

Substance	θ_D(° K.)	γ	Substance	θ_D(° K.)	γ	Substance	θ_D(° K.)	γ
Li	430	1.17	Ag	220	2.40	Ni	375	1.88
Na	160	1.25	Au	180	3.03	Ru	400	
K	100	1.34	Zn	240	2.01	Rh	370	
Be	980		Cd	165	2.19	Pd	275	2.23
Mg	320	1.51	Hg	95		Os	250	
Ca	230		Ga	125		Ir	280	
Sr	170		In	100		Pt	225	2.54
Al	390	2.17	Tl	96	2.73	La	150	
La	130		Ti	350		LiF	650	
Diamond	1850	1.10	Zr	280		NaCl	275	1.63
Graphite	~1500		Hf	213		KCl	230	1.60
Si	625		V	270		KBr	180	1.68
Ge	290		Nb	250		KI	175	1.63
Sn (white)	165	2.14	Ta	245	1.75	RbBr	130	
Sn (grey)	240		Cr	440		RbI	115	
Pb	86	2.73	Mo	375	1.57	CoF_2	475	1.70
Sb	140	0.92	W	315	1.62	AgCl	183	2.12
Bi	110	1.14	Mn	350		AgBr	144	2.28
I	106	0.83	Re	300		MgO	800	
Ne	63		α-Fe	430	1.60	ZnS	270	
A	85		γ-Fe	~320		FeS_2	645	1.47
Cu	310	1.96	Co	385	1.87	PbS		1.94

panying hysteresis effects. Of glassy materials of construction, only elastomers have glass transitions occurring appreciably below room temperature. The transition is faint or nonexistent in Teflon (*11*), a promising cryogenic material.

One of the most troublesome problems facing an equipment designer is the estimation of properties in the absence of experimental data. In the case of heat capacities of the elements and simpler compounds, this reduces to estimation of appropriate θ_D values. These can be calculated (*4*) from the elastic constants, the compressibility, the melting point, the temperature dependence of the reflection of *x*-rays, the temperature dependence of the expansion coefficient, the temperature dependence of the electrical resistivity (for pure metals only), and the wavelength of resonance absorption or reflection in the far infrared (for ionic crystals only). Unfortunately the melting point and expansion coefficient are the only ones of these properties that are more likely to be known experimentally than the heat capacity itself. The formula relating melting point, T_m(° K.), with θ_D is due to Lindemann,

$$\theta_D = 140\left(\frac{n}{V}\right)^{1/6}\left(\frac{nT_m}{M}\right)^{1/2} \qquad (3)$$

where V and M are the molar volume (cc.) and molecular weight, respectively, and n is the number of atoms in the molecule. The formula has been shown to be a good approximation for common metals and cubic binary salts.

The relation between heat capacity and expansivity is discussed more thoroughly in the next section. It is simply noted here that the two are approximately proportional to each other for Debye-type solids.

In an experimental study of alloys, Eucken and Werth (*12*) showed that the specific heat of the copper-nickel alloys can be closely represented by using either the Kopp-Joule additive rule or by using a weighted mean θ_D value, and it seems probable that generally this will be true for simple alloy systems in which all compositions and the parent metals are of the same lattice type and in which the θ_D values of the parent metals are not widely different. The additive rule will fail for alloys having widely different crystal structure and elastic constants from those of either of the major components. An interesting consequence of this argument is that the low-temperature specific heats of the austenitic stainless steels calculated on the additive rule should be based on the heat capacity of γ-iron, the high-temperature phase having face-centered cubic structure. There do not seem to be low-temperature data on the steels with which to test this point.

It will be noted that Equations (1) and (2) give C_v, whereas one desires C_p for most purposes. The difference is given by the thermodynamic expression

$$C_p - C_v = \alpha^2 VT/\beta_T \qquad (4)$$

where α is the expansion coefficient, $\partial V/\partial T/V$ and β_T is the isothermal compresibility, $-(\partial V/\partial P)_T/V$. The relative magnitude of $C_p - C_v$ is usually in the range of 1 to 10% of the specific heat at room temperature, and it decreases rapidly with decreasing temperature. Since low-temperature values of β_T are not usually available, the equation is usually used in the form

$$C_p - C_v = AC_v^2T \qquad (5)$$

in which $A(=\alpha^2V/\beta_T C_v^2)$ is calculated from room-temperature values and is approximately independent of temperature. If, to go one step further, the data are not available for calculating A at any temperature from the above formula, it may be obtained to a less satisfactory degree of accuracy from a formula by Nernst and Lindemann (*13*),

$$A = 0.0214/T_m \qquad (6)$$

for specific heat in cal./(mole)(° K.) and T_m in ° K. Finally it may be admitted that if C_v itself has to be estimated by an indirect method, the accuracy of the resulting heat capacities will probably not be such as to justify taking $C_p - C_v$ into account at all.

Often the property actually desired (as in heat balances) is the enthalpy difference over a large temperature interval, and this is fortunately much less sensitive to estimation errors than is the specific heat.

The simple behavior expressed by the Debye function may be complicated by numerous special phenomena such as phase transformations, Curie points, order-disorder transformations, rotational transitions, glass transitions (e.g., in polymeric materials), transitions between spin states in paramagnetic salts, and, in metals at the lowest temperatures, electronic heat capacity.*

In Table 2 specific heat values of a few technical substances are presented.

* Some of these are described in a review article on heat capacities by P. H. Keesom and N. Pearlman (Flugge's *Handbuch der Physik*, Vol. XIV, p. 282, Springer-Verlag, 1956, in English) devoted primarily to the liquid helium region (*46*).

The values for γ-iron were obtained by Eucken and Werth (*12*) by an indirect method and may be too high since others (*14*) have obtained a value of 0.124 at 373° K. or about 6% less than Eucken and Werth's extrapolated value at this temperature. Similarly if the specific heat of 18 Cr 8Ni steel is calculated by the additivity principle using Eucken and Werth's values for γ-iron, the result at 350° K. is about 3% higher than one experimental value for a nearly identical alloy [(*14*), alloy No. 15] and about 7% higher than another experimental result (*15*). (It is 10% higher than a similar calculation based on α-iron.) The values for 18-8 stainless in Table 2 are adjusted to give a good approximation to the above experimental values and at low temperatures are intermediate between calculated values based on α-iron and γ-iron. The contribution of chromium is uncertain here since this metal normally has a body-centered cubic lattice.

Values derived from expansivity data on stainless type 304 on the assumption of proportionality, the constant of proportionality being adjusted to give the correct specific heat at room temperature, are within 1% of the values in Table 2 down to 150° K. but depart considerably more at lower temperatures as the region is approached where the expansivity becomes anomalous.

The value for Monel at 298° is within 1% of an experimental value (*15*). The entire copper-nickel alloy series has face-centered cubic structure and undoubtedly obeys the additivity principle.

Silica gel is used as an adsorbent and also as a thermal insulation at low temperatures, hence it is unfortunate that there have been no measurements of its low-temperature heat capacity. The heat capacities of fused silica and the various crystalline forms of silica are all about the same, however, and especially so from 100 to 300° K. where they differ by only 4% or less. Thus, it is probably safe to assume that the data on fused silica are representative of silica gel except possibly at the very lowest temperatures where particle-size effects can occur.

Again, experimental data are lacking on Pyrex and other common inorganic glasses. Without a more sophisticated procedure, the data in Table 2 were obtained by linear combination of the specific heats of fused silica and crystalline B_2O_3 (*1*). (Data on B_2O_3 glass do not seem to be available.) These were combined as if Pyrex were a binary 86-14 mixture, thus neglecting any differences that the minor constituents (4% Na_2O, 2% Al_2O_3) might introduce. Expansivities are available but decrease more rapidly with falling temperature than do the data in Table 2, the departure in the ratio of the two quantities from its room-temperature value amounting to 7% at 200° K. and 40% at 100° K. The expansivity of fused silica is anomalous (see next section), and it is unlikely that the correlation between expansivity and heat capacity holds for any silica-base glass.

The data on Teflon are proportional to its expansivity within a variation in the ratio of ±15% down to 80° K. Unfortunately there are no other plastics for which this relationship can be tested.

Coefficients of Thermal Expansion (Expansivities)

Present understanding of the behavior of this property at low temperatures stems from early development by Grüneisen (*16*) of an equation of state for solids based on the lattice dynamics of Debye. It was shown that the dimensionless ratio

$$\gamma = \alpha l'/\beta_T C_v (\text{or } \alpha l'/\beta_S C_p) \qquad (7)$$

in which β_T and β_S are the isothermal and adiabatic compressibilities, respectively, should be a universal constant. Some values of the Grüneisen constant computed from room-temperature properties are given in Table 1, and it will be seen that it has approximately the value 2. The body-centered cubic metals tend toward lower values and average about 1.5, while the face-centered cubic metals are higher and average about 2.3. Within each group there is a tendency for γ to increase with atomic number. The volume and compressibility are both approximately temperature-independent and, since both vary in the same direction with temperature, their ratio is even more constant. Hence if γ were temperature-independent, one could hold that α should vary in proportion to the specific heat, and, hence, should have a temperature variation like the C_v (Debye) curve in Figure 1. This is indeed the case as Figure 2 shows.

Experiments with various metals over extended ranges of temperature are consistent with γ for a given substance being approximately independent of temperature. However, appreciable variations analogous to the variation of the Debye θ with temperature are to be expected and do occur at the lowest temperatures, even in cubic metals.

The simplification of Equation (*7*) to $\alpha \propto C_p$ provides the most useful simple correlation involving the expansivity. Equation (*7*) itself is not very useful for more precisely correlat-

Table 2.—Specific Heats of Some Selected Substances
C_p, cal./(g.)(° K.)

Temperature, ° K.	Al (2)	Mg (2)	Cu (2)	Ni (2)	α-Mn (2)	α-Fe (2)	γ-Fe (12)	Cr (2)	18-8 Stainless *	Monel **	Fused Silica (1)	Pyrex ***	Teflon (11)
20													
(H_2 b.p.)	.0024	.0040	.0019	.0012	.0025	.0011	.0014	.0006	.0011	.0014	.006	.0055	.0183
50	.0337	.0580	.0236	.0164	.0211	.0129	.0218	.0090	.016	.0186	.0272	.0264	.0491
77													
(N_2 b.p.)	.0815	.119	.0471	.0392	.0473	.0343	.0487	.0277	.038	.0417	.0470	.047	.0739
90													
(O_2 b.p.)	.102	.141	.0554	.0488	.0574	.0441	.0604	.0381	.050	.0509	.0570	.0575	.0851
100	.116	.155	.0607	.0555	.0641	.0516	.0684	.0459	.057	.0571	.0643	.065	.0931
150	.164	.202	.0774	.0785	.0872	.0775	.0975	.0757	.085	.0782	.0982	.101	.132
200	.191	.221	.0854	.0915	.1003	.0918	.1118	.0925	.099	.0897	.129	.132	.166
298	.215	.235	.0924	.1060	.1146	.1070	.1251	.1073	.114	.1019	.177	.182	(.248 at 280° K.)

* Calculated on basis 18 Cr 8 Ni balance γ-Fe, then adjusted for agreement with experimental values near room temperature.
** Calculated.
*** Calculated from data for SiO_2 and B_2O_3.

Table 3.—Mean Linear Thermal Expansion of Various Solids

$10^6 \Delta l/l_o$

°K.	Cu	Ni	Al	Mg	Zn	Ti	1020 low Carbon Steel	304 Stainless Steel	Monel	Inconel	Free-machining Yellow Brass	Pyrex	Araldite 501	Teflon
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	1	1	0	0	−1.1	0	0	0	−1	10	30
40	2	1	2	5	9	1	1	−1.5	1.5	1	4	−2	39	90
60	10	4	10	12	28	2	4	+2.8	6	5	15	−1.5	78	160
80	25	12	24	29	57	6	10	14	15	12	34	+1	126	245
100	44	23	46	55	93	14	20	30	29	24	57	4.5	181	335
120	67	38	72	87	133	24	32	50	45	38	85	8.5	242	430
140	92	55	104	124	176	35	47	73	64	55	115	13	310	540
160	119	74	138	164	221	47	63	97	85	74	146	17.5	385	660
180	148	95	175	208	267	60	81	124	107	95	180	22.5	467	805
200	178	117	214	254	314	74	101	151	130	117	214	27.5	556	995
220	209	140	255	303	363	89	121	180	155	140	249	33	651	1,215
240	240	164	297	353	413	105	142	210	180	163	285	39	753	1,440
260	272	188	341	403	465	121	164	241	207	187	322	44.5	862	1,670
280	305	213	385	453	518	138	187	272	234	212	359	50.5	980	1,900
300	339	239	431	503	572	155	210	304	261	238	397	57	1,107	2,460

ing expansivities of a particular substance because compressibility values are often unavailable, especially at low temperatures. The following useful equation not involving the compressibility was obtained by Gruneisen upon assumption of an inverse power interatomic force law

$$\frac{1}{V_o}\frac{\partial V}{\partial T} = \frac{C_v}{Q_o[1 - a(U - U_o)]^2} \qquad (8)$$

Here V_o is the volume at absolute zero, Q_o is the value at absolute zero of the ratio $V/\gamma\beta$, and a is a function of Q_o and the exponents in the law of force. In practice Q_o and a are best evaluated by fitting Equation (8) to actual expansivity data. Without low-temperature data it is still possible to construct the constants from a single room-temperature value of a by adopting for a the approximation $(\gamma + 2/3)Q_o$ and, if necessary, assuming a probable value for γ; thus Equation (8) is reduced to a single constant formula. (Below room temperature $a(U - U_o)$ is usually small compared to unity so that a does not need to be accurately evaluated.) If expansivity data are completely lacking, Q_o may be estimated from a formula derived from Lindemann's melting point equation. This is

$$Q_o = 95nT_m \qquad (9)$$

for an n-atomic molecule, T_m in °K., and Q_o in cal./mole. The formula holds within about 20% for cubic metals but has not been sufficiently tested for other solids. Alternatively, combination of (3) and (9) gives the following expression

$$\theta_D = 14.4\left(\frac{n}{V}\right)^{1/6}\left(\frac{Q_o}{M}\right)^{1/2} \qquad (10)$$

From (10) and (8) it is possible by successive approximations to evaluate θ_D and the specific heat from values of a as a function of temperature for a Debye solid without recourse to values of either compressibility or melting point. A companion formula obtained by integrating (8) gives volume

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changes between any two temperatures, 1 and 2, in terms of the corresponding internal energies.

$$\frac{V_2 - V_1}{V_o} = \frac{U_2 - U_1}{Q_o[1 - a(U_2 - U_1)]} \quad (11)$$

For cubic metals and other isotropic solids including polycrystalline material in which the crystallites are randomly oriented the linear expansivity is

$$\frac{1}{l}\frac{dl}{dT} = \frac{1}{3V}\frac{dV}{dT} \quad (12)$$

and to a good approximation,

$$\frac{l_2 - l_1}{l_o} = \frac{V_2 - V_1}{3V_o} \quad (13)$$

By extensions of Gruneisen's methods the linear expansivities in specific directions in anisotropic lattices can be represented, even including substances like the hexagonal metal, zinc, which has at the lowest temperatures a negative expansivity normal to the principal crystallographic axis (*16*).

Unfortunatley, as has been noted, a number of important technical materials are not Debye-type solids, for example, glass and most plastics. There are few data on these which would permit correlations to be established, and it is doubtful if the foregoing approximation methods are of any value for such substances.

Fortunately, Laquer and Head (*17*) have measured the expansivities of a number of commercial plastics. In general, organic polymers have several-fold higher expansivities than do metals. These may be considerably reduced, even to values similar to ordinary metals, by incorporating into them filler materials of lower expansivity such as glass fiber, asbestos, or inorganic powders. Cloth-reinforced plastics have expansivities in the plane of the reinforcement that are intermediate between the values for the reinforcement and for the matrix, while the expansivity normal to this plane is essentially that of the plastic matrix.

Glass transformations or other singularities should appear in the expansivity in much the same way as in the specific heat. A noteworthy example is the first-order transition in Teflon which occurs at about ambient temperature.

A number of substances show an anomalous negative expansivity at low temperatures, not merely in one crystallographic direction as with zinc, but also in the *average* linear or the volume expansivities. Among these are uranium, type 304 stainless steel, fused silica, and Pyrex. Fused silica, of course, is a unique material, having an extremely small expansivity which at low temperatures is variable among samples.

Expansivities of a number of selected metals and technical materials are given in Table 3. These data were obtained from (*17*) and from a useful literature survey with selected data by Laquer (*18*). Araldite 501 is included as belonging to a class of materials, the epoxies, that finds cryogenic use as adhesives.

Part 2 will follow in the July issue.

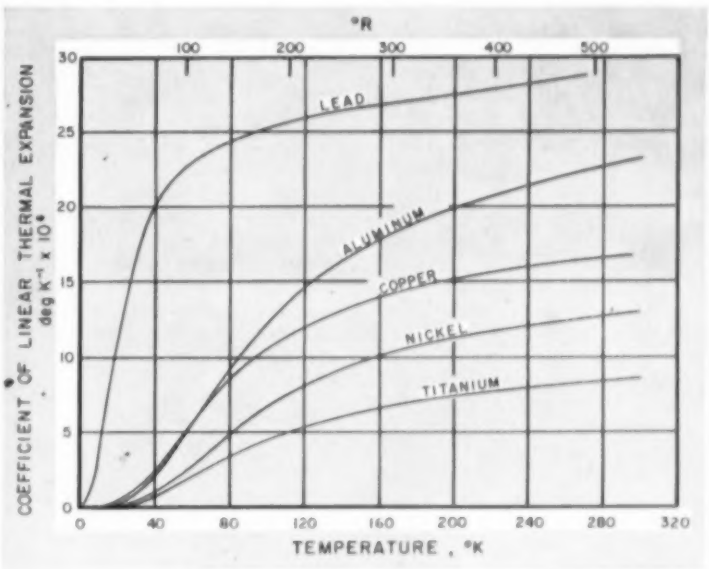

Fig. 2.

Notation

C_p = molar heat capacity at constant pressure
C_v = molar heat capacity at constant volume
$D(\theta_D/T)$ = Debye function [defined in Equation (2)]
$E(\theta_E/T)$ = Einstein function [defined in Equation (1)]
K = thermal conductivity
L = Lorenz ratio, $K\rho/T$
M = molecular weight
Q_o = a material constant defined as $(V/\gamma\beta)_{T=0}$
R = the universal gas constant
T = absolute temperature
T_m = melting point, ° K.
U = molar internal energy
U_o = molar internal energy at $T = 0$
V = molar volume
W = thermal resistivity, $1/K$
n = number of atoms in molecule
l = length

Greek Letters

a = thermal expansion coefficient, $\frac{1}{V}\frac{\partial V}{\partial T}$
β_T = isothermal compressibility, $-\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T$
β_s = adiabatic compressibility, $-\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_s$
γ = Grüneisen's constant [defined by Equation (7)]
θ_D = the Debye characteristic temperature
θ_E = the Einstein characteristic temperature
λ = phonon mean free path
ρ = electrical resistivity

Subscripts

subscripts on K, W, and ρ

o = at $T = 0$
∞ = at about room temperature (actually at $T > \theta$)
i = ideal component at temperature, T
$i\infty$ = ideal component at about room temperature ($T > \theta$)

Conversion Factors

1 w./(cm.)(° K.) = 0.239 cal./(sec.)(cm.)(° K.)
1 w./(cm.)(° K.) = 57.8 B.t.u./(hr.)(ft.)(° F.)
1 w./(cm.)(° K.) = 693 B.t.u. (in.)/(hr.)(sq.ft.)(° F.)

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GAS PREPURIFICATION for LOW TEMPERATURE PROCESSING

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Low temperature is a relative matter. Just how relative is forcefully demonstrated by the relationships given in Figure 1, which shows the temperature scale from the freezing point of water down to absolute zero. Three scales are included: degrees Kelvin, degrees Centigrade, and degrees Fahrenheit. At the top is the freezing point of water, 273° K., 0° C., or 32° F. On the left are plotted the boiling points of a number of familiar materials, all of which are gases at normal temperatures and pressures. On the right are shown the freezing or sublimation points of some of these same materials as well as of some others. The relation of these points to one another is the key to the need for prepurification. For example, to liquefy methane (natural gas), it is necessary to remove water and carbon dioxide since each of these will freeze at the temperature required. The same is true when liquefying oxygen or nitrogen in an air-separation plant; in this case, acetylene and other hydrocarbons must also be removed to avoid additional difficulties.

Going down the scale, one comes to hydrogen which liquefies at about 20° K. or −423° F. At this point nitrogen and oxygen are contaminants which must be removed. Finally, helium liquefies at 4.2° K. At this temperature, more than 452° below zero Fahrenheit, all other elements are solids. It is said that under these conditions oxygen and nitrogen, in appearance and mechanical behavior, resemble white sand at ordinary temperatures (*15*).

Thus, gas prepurification is of vital importance to low-temperature processes since accumulation of solids by freeze-ups can soon render low-temperature equipment inoperative. For example, many low-temperature processes use expansion valves or orifices to cool the gases further by the Joule-Thompson effect. Solids present at that point in the cycle soon would plug up the valve or orifice and thus cause a shutdown. Similarly, heat exchangers used in low-temperature processing can be plugged easily since they generally are made up of relatively small-diameter tubing. Therefore, it is necessary either to remove the impurities from the gases prior to the low-temperature equipment, or to design the heat exchangers for deliberate freezing-out of impurities and subsequent removal by reverse flow. Despite best efforts toward prepurification, some accumulation of solids such as water or carbon dioxide is inevitable, and the equipment must be shut down for thawing out or "deriming" as it is called in the industry. However, the interval of time between derimings can be extended by adequate prepurification to an extent such that shutdowns can be timed to coincide with other maintenance work.

In general there are three methods for removing impurities from gases:

1. chemical reaction
2. absorption and adsorption
3. freeze-out

In the first group are processes in which the gas to be purified is washed with a solution which will react chemically with the impurity and thus remove it from the system. An example of this is the removal of carbon dioxide by reaction with sodium hydroxide to form sodium carbonate.

An example of the second group is the use of activated alumina in a solid dessicant system for removing water vapor from gas.

The third method borders more closely on low-temperature processing than on prepurification in that the heat exchangers used for initial cooling of the gases to be processed collect the materials by freezing them out of the gas. After freezing, the solids collect either on the surface of the heat exchangers or in a filter downstream from the exchanger.

Air Purification

The widest application of low-temperature processing is the separation of the two major components of air: oxygen and nitrogen. As far as prepurification is concerned, the major contaminants to be removed are water and carbon dioxide since both will freeze at liquid air temperatures. In addition, traces of acetylene and other hydrocarbons, if not properly handled, will accumulate in the system and may cause an explosion.

CARBON DIOXIDE REMOVAL

Atmospheric air generally contains about 330 p.p.m. CO_2. This is not a large amount, but over a period of time it is sufficient to plug the low-temperature heat exchangers. Several methods are available for removing carbon dioxide down to less than 3 p.p.m., which is considered an acceptable value for air separation. These are:

1. Caustic Alkali Wash

Generally a water solution containing 5-10% NaOH by weight is used. However, potassium hydroxide can also be used and actually has a higher absorption coefficient. The air is first compressed, then passed through a filter and oil trap, and into a packed column where it flows countercurrent to the recirculating caustic solution.

The system is simple to operate and requires only that the pump be kept in operation and that more caustic be added to the solution to make up for that which has reacted with the carbon dioxide to form sodium carbonate. From time to time the solution must be discarded to keep the carbonate content from building up too high. Since the system is aqueous, the air leaving the scrubber will be saturated with water vapor at the pressure and temperature of operation.

2. Absorption and Adsorption

In certain applications it is desirable to use a dry system for carbon dioxide removal. In such plants the air to be purified can be passed through beds of solid alkalis such as potassium hydroxide and sodium hydroxide. One of the materials used, referred to as soda lime, is a mixture of calcium, sodium, and potassium hydroxides. The reactions are the same here as with caustic solutions and, when the beds have become exhausted, the material must be replaced. In general the liquid processes are preferred since dry chemicals are more difficult to handle and tend to cake up in the vessel when they get moist.

Another dry process is adsorption of carbon dioxide on activated carbon, alumina, silica gel, and other surface-active materials. In these units the adsorbent generally is placed in two vessels which are alternately regenerated by warming.

3. Freeze-out Processes

Despite the efficiency of chemical

processes for carbon dioxide removal, methods that do not require the supply and handling of chemicals are attractive in principle. This is particularly true for units that must be mobile, such as on shipboard or airborne, or which are located remotely, since the only operating requirements would be a source of power and perhaps cooling water for the air compressors. Furthermore, in low-pressure cycle oxygen plants chemical purification becomes expensive and cumbersome.

In general two types of equipment have been used for removing carbon dioxide as a solid: regenerators and reversing heat exchangers.

Regenerators were conceived by Mathias Frankl in Germany as a method of precooling and purifying the incoming air by passing it through a vessel packed with a material capable of storing heat. Two pairs of regenerators are used alternately, one pair on the product oxygen stream and one pair on the product nitrogen. In practice the cold oxygen and nitrogen streams pass through these vessels and cool the packing. The incoming air splits and flows through the alternate oxygen and nitrogen regenerators which have previously been cooled. In the regenerators, which are generally packed with pancakes of spirally wound corrugated metal strips, the water vapor and carbon dioxide condense and solidify on the surface of the packing. The water deposits at the warm end and the carbon dioxide at the cold end. After a given period of time, perhaps 15 min. or less, regenerators are switched and the product oxygen and nitrogen pass out through the regenerators containing the solidified water and carbon dioxide. Since these product streams are at lower pressure than incoming air, water and carbon dioxide are purged out of the regenerators while they are being cooled down for another cycle.

In practice, the regenerator-type oxygen plant such as the Linde-Frankl still requires that a small fraction of the air be purified chemically; thus, this equipment is not entirely eliminated. Other disadvantages are that the product oxygen and nitrogen are of necessity contaminated with water and carbon dioxide as well as with residual air left in the regenerators from the previous cycle, and that, toward the end of the cycle, the incoming air is somewhat warmer which allows more carbon dioxide to enter the air-separation plant. A solution to this problem was found in the so-called reversing exchangers. Operation is as follows:

Reversing Exchanger Operation—W. E. Lobo and G. T. Skaperdas (*11*).

The air to be fractionated is cooled in counterflow in one of the two similar passages against the waste nitrogen in the other similar passage, while the oxygen product and unbalance stream flow uninterruptedly in their two passages. As the air is cooled, it deposits water, ice, carbon dioxide, and other impurities. Since this would eventually block the exchanger, the reversing valve, operated periodically by an electric timer, diverts the air into the passage which had been carrying nitrogen, and the check valves respond so that they direct the nitrogen into the passage which had been carrying air. It may be noted that the direction of flow of gas in either reversing passage is reversed as a result of the operation of the reversing valve, but that each gas always flows in the same direction, first in one passage then in the other. Since the nitrogen is one of the products of the separation, it is at a lower pressure than the air. Hence, the capacity of the nitrogen to hold water or carbon dioxide in the vapor state is larger than that of the air at the same temperature. Therefore, as the nitrogen passes over the impurities which the air had deposited on the exchanger surface, the impurities are evaporated into the nitrogen and are carried out of the exchanger. Thus, the air is delivered from the exchanger in a cold, purified condition, while the nitrogen carries the condensed impurities away from the exchanger so the cycle can be repeated indefinitely. The time between reversals of flow is about three minutes. The two reversing passages must be similar in flow resistance so that the back pressure on the nitrogen, and therefore on the fractionation system, may remain constant on both phases of the cycle. This is desirable for the fractionation.

It may be noted that the oxygen flows through its passage continuously, and that the passage is never contaminated with air or its components. The oxygen is, therefore, delivered pure and very dry, as its dew point is about —300° F.

Since the nitrogen purges the exchanger of precipitated impurities, it may be referred to as the scavenge nitrogen.

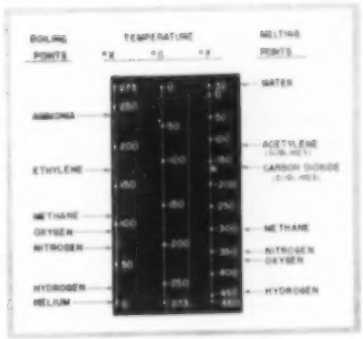
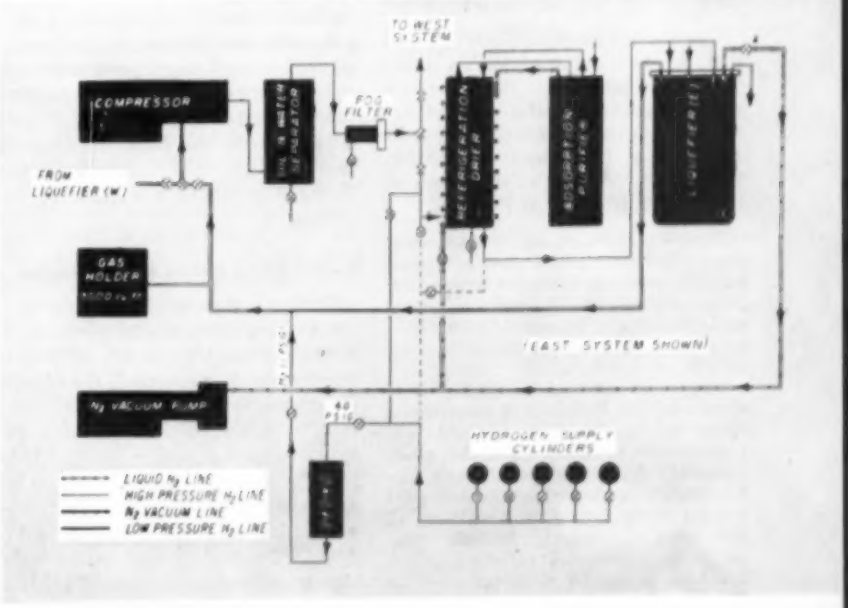


Fig. 1. Boiling points of different materials related to Kelvin, Centigrade, and Fahrenheit scales.

WATER REMOVAL WITH SOLID DESSICANTS

Air to be fractionated is first compressed to the operating pressure of the air-separation plant. Some water may be condensed out in the aftercooler of the compressor; this depends upon the humidity of the air at the time and the pressure used. When this is followed by a caustic solution wash, the air is saturated with water vapor at the operating pressure and temperature. Even at high pressure this amount of water vapor is too much for the operation of the low-temperature cycle and must be reduced appreciably.

Fig. 2. Flow diagram of the hydrogen liquefier at the NBS-AEC Cryogenic Laboratory.



General practice in air-separation plants using chemical purification is to use a solid-dessicant-type dryer which consists basically of two alternately used vessels containing activated alumina, bauxite, or silica gel. Here one vessel operates on the dehydration cycle while the other is being regenerated by heating and purging with dry air. A dew point as low as −100° F. (referred to atmospheric pressure) may be obtained in such equipment; this is generally considered adequate for low-temperature processing.

HYDROCARBON REMOVAL FROM AIR

In addition to water and carbon dioxide, the air around many industrial operations will contain small amounts of acetylene and other hydrocarbons. These will accumulate in poorly designed low-temperature systems and can cause explosions (*9, 12*). Two methods are available for removing these materials by prepurification: (*1*) catalytic oxidation of the hydrocarbons to carbon dioxide and water, or (*2*) by adsorption on such materials as activated carbon and silica gel (*14*). Both processes have the disadvantages of being bulky for large-scale plants and of being subject to accidental break-through of the hydrocarbons; these have not been used generally up to this time. More frequently, hydrocarbons are removed within the low-temperature cycle by adsorption, filtration, or scavenging. However, recent accidents in large-scale oxygen plants have resulted in renewed interest in catalytic oxidation for prepurification.

Purification of Hydrogen for Liquefaction

One method for liquefying hydrogen that has received considerable attention in the literature is the high-pressure process used by the National Bureau of Standards in their Cryogenic Engineering Laboratory at Boulder, Colorado (*1, 2, 3*). A flow scheme of this process is shown in Figure 2.

Here the hydrogen supply is obtained from cylinders or tube trailers of electrolytically produced hydrogen which contains small amounts of oxygen and nitrogen. The oxygen is removed before compression and the nitrogen after compression.

Oxygen is removed by causing it to react with the hydrogen to form water. There are several catalysts which will promote this reaction. Metallic nickel chemically deposited on an extended surface support such as alumina is a good catalyst when heated to about 300° C. An effective catalyst, available commercially, consists of palladium which has been chemically deposited upon an extended surface support. This catalyst, which is used at Boulder, is operative at ordinary room temperature and 50 lb./sq. in. Its principal disadvantage is that it is temporarily deactivated (poisoned) by such impurities as hydrocarbons or carbon monoxide, and that it is permanently deteriorated by chlorine. The hot nickel catalyst is less subject to these objections (*8*).

Following the deoxidation step, the gas is compressed to about 2000 lb./sq. in. in reciprocating compressors and cooled with cooling water in the aftercooler which reduces the dew point of the hydrogen sufficiently for further processing. An oil-and-water separator packed with bronze wool followed by a fog filter is included downstream from the compressors to remove any entrained water and lubricating oil from the hydrogen.

The next step is the complete removal of water vapor and oil by a freeze-out process (Figure 3). Hydrogen enters the coil in the refrigeration dryer at room temperature and is cooled by countercurrent heat exchange with cold hydrogen returning from the next step. Water and oil are condensed out and freeze in the coil. From here the hydrogen passes into a second heat exchanger coil that is immersed in a bath of liquid nitrogen in the purifier vessel. Here again heat exchange with the outgoing hydrogen is performed. After reaching nearly liquid nitrogen temperatures (about −320° F.) the hydrogen is passed through a coil containing silica gel which is also immersed in liquid nitrogen. This coil is 3-in. diam. and 60 ft. long. At this point the nitrogen present is adsorbed on the silica gel and the hydrogen then is pure enough for liquefaction. In practice about 300 cu. ft. N_2 can be absorbed on the silica gel before break-through when a normal amount of nitrogen, about 500 p.p.m., is present in the hydrogen. Since the coil contains about 3.7 cu. ft. of silica gel, this amounts to better than 80 cu. ft. N_2/cu. ft. of silica gel (*8*).

The refrigeration dryer and the silica gel purifier are installed in duplicate in this plant, one being regenerated while the other is in operation. Regeneration is accomplished by removing the liquid nitrogen from the bath, warming up the silica gel coil with an electric heater, and pulling a vacuum on the system.

Purification of Helium for Liquefaction

In the liquefaction of helium for low-temperature experimental purposes, it is also necessary to get rid of impurities that would freeze up in the system. Commercially available helium, however, is fairly pure already and the only treatment generally required is to pass the helium at about 500 lb./sq.in. over activated carbon in a drum immersed in liquid nitrogen (Figure 4). This is the method used in the well-known Collins helium cryostat (*6, 10*).

Industrial Gas Purification Processes

1. GIRBOTOL PROCESS

The caustic wash used for removing small quantities of carbon dioxide found in air is not economically feasible for bulk removal of carbon dioxide from natural and manufactured gases although it is frequently used for final cleanup. The process now used by the Bureau of Mines in its present helium production plants, is described here in part:

Girbotol Process—P. V. Mullins (*13*). Helium is extracted from helium-bearing natural gases at low temperatures and elevated pressures, a combination which results in liquefaction of all constituents of the gases except helium, the most difficult of all gases to liquefy, and permits its extraction and recovery by simple phase separation. The operation is among the few which utilize extremely low temperatures, particularly in combination with high pressures and relatively high gas-processing rates. Process temperatures range downward to −310° F. and pressures upward to 2,700 lb./sq. in. Since most gases processed for helium extraction contain only 1 to 2% He, large quantities of gas must be processed. Individual Bureau of Mines plants have daily gas-processing rates ranging upward to 30,000,000 cu. ft. natural gas/day.

In the Girbotol process, a solution of approximately 18% monoethanolamine, 70% diethylene glycol and 12% water is pumped into a bubble tower for contact with the gas under 600 lb./sq. in. Rich solution containing absorbed acid gases and water is passed continuously from the contactor to a bubble-tower still for reactivation at about 280° F. and then recirculated. . . .

After passage through the contactor the natural gas (still at about 600 lb./sq. in.) is passed through beds of 4-8-mesh solid adsorbent (activated bauxite) for final dehydration. . . .

Natural gas, initially containing 0.6 to 0.8% CO_2 and/or H_2S, contains negligible amounts of these constituents following treatment. Depending upon the sustained efficiency and the switching frequency of the batch adsorbers used for final dehydration, the treated gas contains very little or no water vapor. Helium separation units have been operated continuously for several weeks without shutting down to thaw carbon dioxide ice or water-ice formed in the equipment.

Another application of the Girbotol process is the removal of carbon dioxide from a crude gas mixture prepared by the hydrocarbon reforming prior to the low-temperature separation of carbon monoxide and hydrogen.

2. COKE OVEN GAS PURIFICATION

One of the earliest applications of

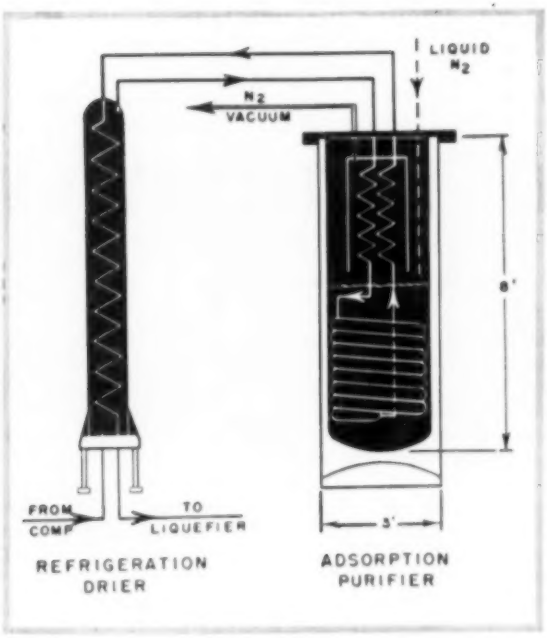


Fig. 3. Flow diagram of the freeze-out process for removal of water vapor and oil.

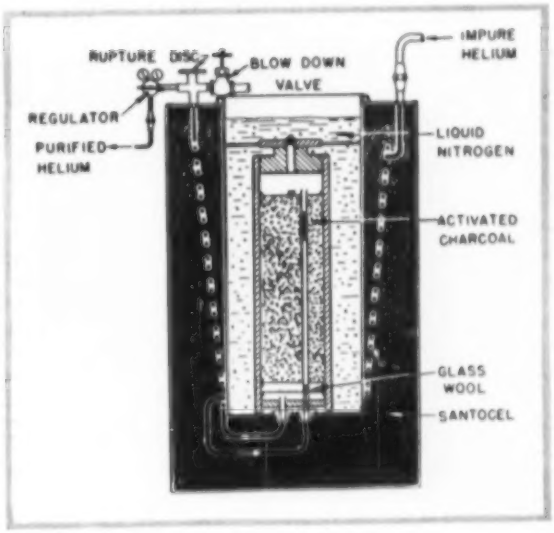


Fig. 4. Liquid nitrogen charcoal trap.

low-temperature processing in the chemical industry was its use in separating hydrogen from by-product coke-oven gas for use in ammonia synthesis. Claude first accomplished this in 1922 in France and was soon followed by Linde and Messer in Germany (*7*). The composition of coke-oven gas will vary somewhat with the coal used. However, even the best of it contains a number of impurities which must be removed prior to low-temperature processing. These include such materials as tar, oil, benzene, naphthalene, hydrogen sulfide, hydrogen cyanide, and carbon dioxide.

A number of processes have been used in Europe for this purpose but until recently they have not proven attractive in the United States. However, the first plant in this country to produce ammonia from coke-oven gas was put on stream at Birmingham, Alabama, by Ketona Chemical Company in 1956. The low-temperature operations are used not only for removing carbon monoxide from the hydrogen by liquid nitrogen wash by the Air Liquide process, but also for separating out by-product streams of methane and an ethane-ethylene mixture.

Prepurification at this plant is described as follows:

First raw coke-oven gas (after electrostatic and soda ash treatments) is compressed to 300 lb./sq. in. gauge and 220° F. It then goes to a "hot bottle" where high molecular weight contaminants polymerize into gummy tars and condense on the tower walls.

The gas is scrubbed with a light petroleum oil to remove aromatics, then with a 3% ammonia solution for CO_2 and sulfur. This is followed by a cold-water wash and a caustic solution scrub to get rid of the last traces of CO_2. The gas goes to the nitrogen scrubbing unit, then to ammonia synthesis.

3. AMMONIA SYNTHESIS GAS PURIFICATION

Another aspect of ammonia synthesis gas purification by low-temperature processing is the liquid nitrogen wash scheme being used in some ammonia plants, particularly those that produce hydrogen from the partial oxidation of natural gas or fuel oil with oxygen by the Texaco process. A liquid nitrogen wash is used in these units for removing residual carbon monoxide, which is poisonous to the ammonia synthesis catalyst, and methane, which builds up as an inert in the system and reduces the yield of ammonia. Although there are other processes available for effecting this final purification, it is particularly convenient in these plants to use nitrogen since it is available from the oxygen plant.

The major impurity found in the gas stream in this case is carbon dioxide which, in the case of plants starting with fuel oil, amounts to more than 30% of the crude gas volume. In such a case, processes for the bulk removal of carbon dioxide, such as water scrubbing or the hot potassium carbonate process developed by the U. S. Bureau of Mines (*5*), are generally more economical than the Girbotol process. However, they must be followed by a cleanup process, such as a caustic wash or Girbotol followed by caustic wash since they will not reduce the carbon dioxide content of the gas low enough.

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This review concerns the unusual features of distillation columns built to operate at liquid air temperatures and discusses the special problems encountered by their designer. The data available to such a designer and the methods of applicability comprise the major part of this article.

LOW TEMPERATURE DISTILLATION

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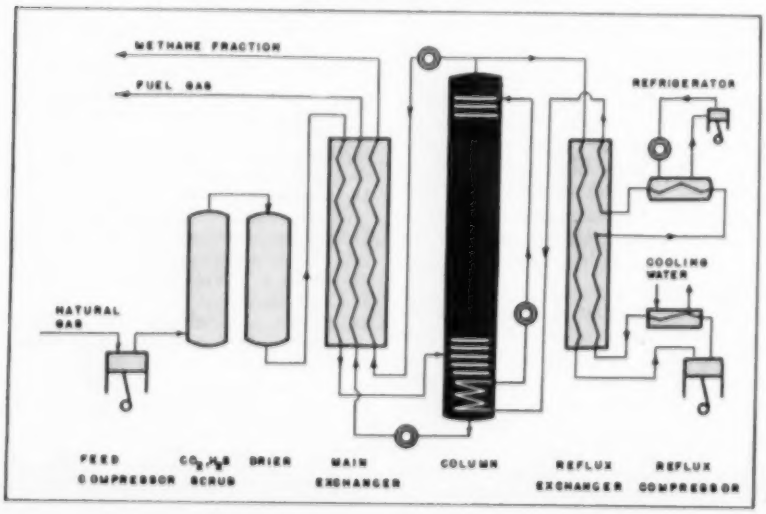
The typical low-temperature process separates the components of a normally gaseous mixture. Usually this is done by liquefying part of the feed gas and distilling it. Examples include the separation of O_2 from air, the purification of H_2 from refinery gases, and the removal of pure CH_4 from natural gas.

The methane purification process, as shown in Figure 1, demonstrates the interdependence of process design and column design. It also emphasizes the difficulty of obtaining reflux for low-temperature distillation columns. Here the natural gas feed is chemically scrubbed to remove CO_2 and H_2S, dried by adsorption, cooled in countercurrent heat exchange with the product gases, and passed into a distillation column. The column produces a bottom fraction containing C_2 and heavier hydrocarbons and a distillate of CH_4, H_2, and N_2. Recycle for this column is obtained by taking part of the distillate stream, warming it to ambient temperature, compressing it, and removing the heat of compression with cooling water, and recooling it. Final cooling and partial liquefaction are obtained by using this stream as a heat source in the column reboiler. It is expanded then to column pressure and injected into the column as reflux. The column is operated under about 100 lb./sq.in. gauge so that both column products, after Joule-Thompson expansion, may be used to cool and liquefy the gas feed. The process cycle used to obtain column reflux is necessary because the top of the column is colder than any of the fluid streams that might be available as coolants unless these streams are cooled by expansion to a lower pressure. Supplying reflux to this column represents a major part of the total operating cost. This is typical of low-temperature processes and explains why columns in these plants usually operate close to the minimum reflux.

Another Solution to Reflux Problem

A different solution to the problem of reflux supply is found in a typical air-separation plant. Here the problem of supplying reflux to the column is met by carrying out the distillation at two pressures. Air at its dew point is fed to the bottom of the lower column which operates at 6-7 atm. p. From the bottom of this column a "crude oxygen" liquid containing 35-40% O_2 is removed. Relatively pure N_2 is removed from the top of this column. Reflux is obtained through condensing the N_2 by using its energy to boil the oxygen in the sump of the upper column. Thus the pressure difference between these two columns must be such that the N_2 in the high-pressure column condenses at a temperature higher than the boiling temperature of O_2 in the low-pressure column. A ΔT across the condenser-reboiler of 5-10° F. is normal. Thus 90 and 20 lb./sq.in. abs. are normal pressures for the high- and low-pressure columns respectively, giving a 6° F. ΔT across the condenser-reboiler. After subcooling and expansion the crude oxygen is used as feed to the low-pressure column. The N_2 from the high-pressure column after similar subcooling and pressure reduction forms the low-pressure column reflux. It is evident that the design of this column is closely integrated with that of the process as a whole. Reflux ratios and feed conditions for the two parts of the column are not only interdependent but also are functions of the purity of the products, the arrangement of the over-all cycle, the effectiveness of the heat exchangers, and the operating range and efficiency of the expansion engine. This interdependence is not so marked in the design of high-temperature columns where reflux can be made at the expense of cooling water, and where process steam serves to heat the reboiler.

Fig. 1. Flow diagram of methane purification plant.



The relations between column streams in an air-separation plant are shown best with the aid of an H-x diagram. Here air is assumed to contain only O_2 and N_2 and hence the results obtained are only qualitative when oxygen purities above 95% are being produced, but the principles are well illustrated. Figure 2 shows such a diagram. On it are plotted saturated liquid and vapor loci for both the low- and high-pressure column pressure. The feed to the high-pressure column enters at concentration $x_F = .79$ mole fraction N_2. Its enthalpy depends on the external process, but here it is assumed to be h_F, such that the feed is 10% liquid. The crude oxygen con-

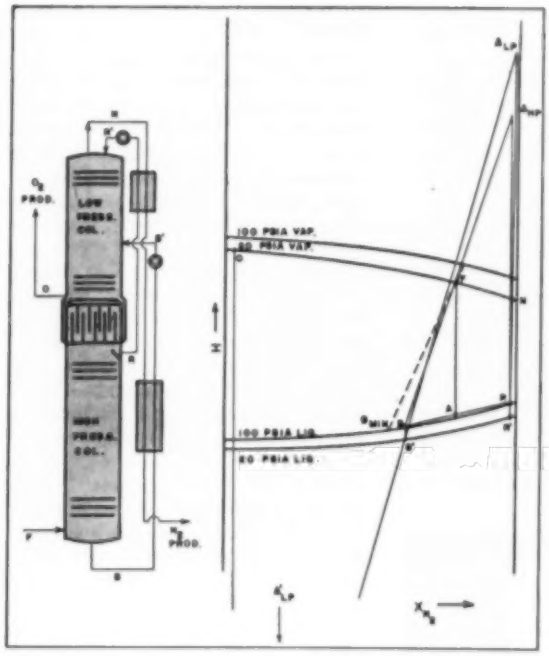


Fig. 2. Enthalpy-composition relationships for a double column.

Fig. 3. Ammonia synthesis gas plant under construction.

centration and enthalpy must fall at point B to the right of the high-pressure connodal through F. Choice of this concentration and that of the "crude N_2," R, fixes the difference, or net flow, point for the high-pressure column. The number of theoretical stages required can be readily determined. This is either done directly on the H-x diagram by the Ponchon-Savarit stepwise construction, or by using the difference point and saturation curves from the H-x diagram to construct an operating line on an x-y diagram. The stages then may be stepped off by the McCabe-Thiele procedure. The operating line so constructed will be slightly curved due to the variation in latent heat of O_2-N_2 mixtures with concentration (*30*).

The crude N_2 and crude O_2 streams are fed to the low-pressure column after subcooling and expansion. The amount of subcooling depends upon external cycle conditions and on the temperature approach in the subcoolers. It can be assumed that the subcooling is represented by lines B-B' and R-R' and that both O_2 and N_2 products from the low-pressure column are saturated liquids. This completely specifies conditions in the low-pressure column since the heat input to the reboiler has been determined by conditions in the high-pressure column. By an energy balance around the high-pressure column:

$$h_F F + Q = F(h_F + Q_F) = h_R R + h_B B$$

where

F, R, B = mass of streams F, R, and B

h_F, h_R, h_B = enthalpy of streams F, R, and B

Q = heat added in the condenser-reboiler

Q_F = heat added in the condenser-reboiler per unit mass of feed

Thus the distance F-A represents Q_F. Q_{O_2} can be obtained from the relation

$$Q_{O_2} = Q_F \times \frac{F}{O_2}$$

where

Q_{O_2} = heat added in the condenser-reboiler per unit mass of oxygen product

Now the difference, or net flow, points for the low-pressure column can be determined. Δ'_{LP} is at the coordinates $(x_{O_2}, h_{O_2} - Q_{O_2})$. The relationships:

$$\Delta_{LP} = N + R'$$

and

$$B' = \Delta_{LP} + \Delta'_{LP}$$

written both as material balances and energy balances fix Δ_{LP} at the intersection of the lines passing through N and R' and through Δ'_{LP} and B'. With these difference points the determination of the number of ideal stages required is carried out as was done for the high-pressure column. If the solution here obtained is impractical or impossible at any point, the designer can adjust any of the variables that he has arbitrarily fixed. These are the condition of the air feed, the concentration of the crude O_2 and N_2 streams, and the extent of subcooling. Changes in any of these will affect the process external to the column itself.

Ingenuity of Designer

In this discussion it has been presumed that the column will operate adiabatically. Actually this can never occur. In high-temperature columns heat losses result in the creation of additional reflux through the column; this requires greater reboiler capacity but otherwise aids the separation. In low-temperature columns heat is gained from the surroundings. This reduces the column reflux and makes the separation more difficult. The resulting penalties in terms of reduced separation efficiency and increased refrigeration requirement are large. The designer cuts this loss by heavily insulating the plant and by building it as compactly as possible. The column, heat exchangers, and interconnecting piping are clustered inside the framework of the cold box. This will be covered with steel plate and packed with insulation. Figure 3 shows an ammonia-synthesis gas plant in construction stage. Here, despite the desirability of a compact unit, the column is about 40 ft. high. This is considerably taller than the heat exchangers that are nestled around it.

Heat Leak and Design

In the design of the plant the unavoidable heat leak is divided between the individual plant components in proportion to their surface area and to the ΔT from their surfaces to ambient. The total heat leak will vary from about 1 B.t.u./lb. of feed in large plants to five times this in small plants. That part which is assumed to reach the column (about half the total in air plants) is usually assumed to enter the top of the column; thus the position of Δ_{LP} is lowered. This is generally the most conservative approach since the loss in reflux is felt throughout the column.

The interdependence of column and process design then puts the following criteria on the column itself:

1. It should operate close to minimum reflux, and therefore needs a large number of theoretical stages.
2. It should be as compact as possible so that the heat leak can be kept at a minimum.
3. It should be precisely designed, for operating conditions cannot easily be changed to compensate for poor column design. If such changes can be made, they usually result in greater refrigeration requirements and hence higher operating costs.

To meet these criteria, the column designer has tried to get many physical distillation plates into a column having minimum external surface. Plate efficiencies could not be sacrificed in these efforts. The solution has been to design the column with the minimum possible tray spacing, sometimes going as low as 1½ in. between trays. Efficient gas-liquid contacting has been obtained through the use of thimble-sized bubble caps or by sieve plates with holes of about ⅛-in. diam. spaced on about ⅜-in. equilateral triangular centers. Figure 4 shows a typical bubble-cap plate. This plate is used in the low-pressure column of a plant producing 7,000 std. cu.ft./hr. of 99.98% O_2. The column is made by fitting together a stack of these plates much as particle sizing screens are stacked as shown in Figure 5.

Figure 6 shows a typical sieve plate. This plate was used in a column separating refinery gases by liquid N_2 washing to produce ammonia-synthesis gas.

The ability to separate efficiently at low tray spacings arises from the properties of the fluids being separated. These are generally of low viscosity (generally less than 1 centipoise), low-surface tension (about 1/5 that of water), nonfoaming, and free from contained solids. Little information is available on the foaming behavior of low-temperature liquids. Linde (*26*) has observed the action on distillation trays separating oxygen-nitrogen, oxygen-argon, and nitrogen-argon mixtures. He found that at N_2 concentrations between 20 and 90% in either O_2 or A the liquid foamed. At higher N_2 concentration or in systems low in N_2 no foaming occurred. The foam Linde observed rarely exceeded 1 in. in depth, and he concluded that its major effect was to promote improved gas-liquid contacting. This was substantiated by separation effectivenesses that he found to fall off at low N_2 concentrations. Similar studies have not been made for other low-temperature systems. The information available does however indicate that low-temperature distillation columns generally operate with up to 10% entrainment ratio.

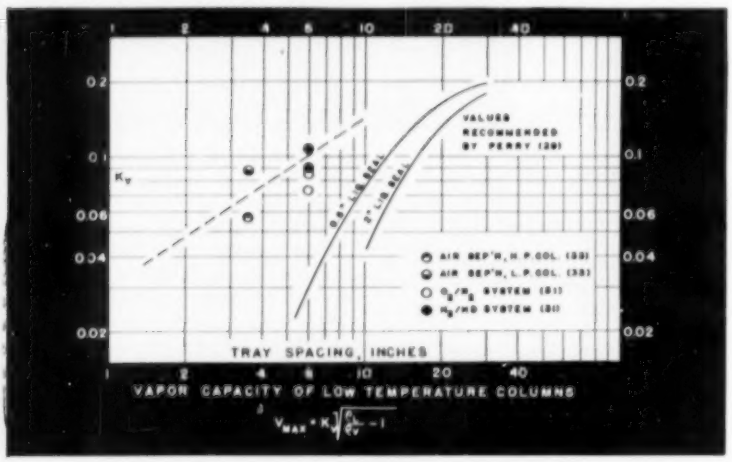


Fig. 7. Maximum vapor capacity of low temperature column.

$$K_V = \frac{V_{max.}}{\sqrt{\frac{\rho_L}{\rho_V} - 1}}$$

No Published Data on Low-Temperature Column

The detailed plate design for low-temperature columns is carried out in the same manner as is that for high-temperature columns. There is not, however, a fund of published capacity and performance data such as is available for high-temperature columns. Factors in such a design include the capacity of the column for vapor flow, pressure drop of vapor passing through the plate, liquid flow resistance across the plate and through the downcomers, and minimum vapor and liquid loadings required for effective contacting. The usual approach to limiting column capacity based on maximum allowable vapor velocity is used in the design of these columns. Published data on the capacity of low-temperature columns are shown plotted as K_V vs. plate spacing in Figure 7 (*29*). K_V is the proportionality constant in the relation:

$$V_{max.} = K_V \sqrt{\frac{\rho_L - \rho_V}{\rho_V}}$$

where

$V_{max.}$ = maximum allowable vapor velocity, ft./sec.

ρ_L, ρ_V = densities of liquid and vapor, lb./cu.ft.

K_V = a function of plate spacing and liquid depth, ft./sec.

Data (*32, 34*) indicate that considerably greater vapor flows may be handled than is common practice in high-temperature columns. This indication is strengthened by plant-performance information. The dashed line shown gives approximately the capacity relation used by low-temperature column designers. No published information can be found on the pressure drop due to gas or liquid flow across low-temperature plates. The designer uses the relations for high-temperature columns adjusted for differences in physical properties of the fluids.

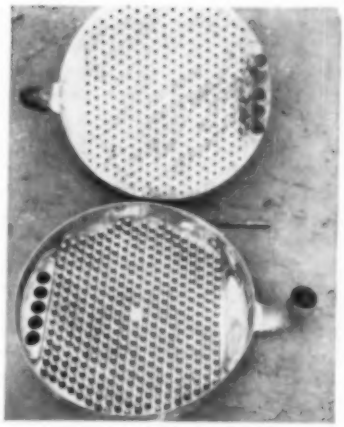
The low tray spacing makes the column especially sensitive to hydraulic gradient so that the liquid velocity must be kept low. Fortunately, the low-liquid viscosity tends to reduce the hydraulic gradient. Even so, large columns are frequently segmented into many smaller plate sections complete with downcomers from above and to the plate below. This greatly reduces the length of liquid path and hence the hydraulic gradient. Figure 8 shows such a segmented distillation plate during assembly into the column. Each of these triangular sections is a complete tray in itself with each side 18 in. long. Two plate levels are shown here, the plates in the foreground being below those to the rear. Liquid flows from the center to the corners on the foreground trays and from the

corners to the center on the rear trays. Plate spacing is 4 in. Figure 9 is a view of the top plate of the high-pressure column showing how reflux is distributed to the tray sections, while Figure 10 shows the condenser-reboiler for this column.

In sieve trays the hydraulic gradient is much less critical due to the unobstructed liquid flow path so that such segmenting is rarely necessary. For this reason as well as for their simplicity and lower cost, sieve plates are becoming the common practice for low-temperature separations. As in high-temperature columns they are found to have slightly higher capacity for both liquid and vapor and slightly better efficiency than do bubble-cap trays. A well-designed sieve tray will weep at about one third of its maximum vapor flow rate. This gives an adequate operating range. The problem of hole-clogging is completely absent unless frozen matter collects in the column. Such build-up of solids, usually CO_2, occurs almost inevitably and requires occasional shutdown and deriming of the plant. In many plants with effective precleaning of the gas feed this is only necessary yearly.

For these columns the calculation of tray requirements is made through exactly the same techniques as those used for high-temperature columns. Essentially all low-temperature separations involve more than two components. Basically then the calculations require the use of step-wise plate-to-plate trial-and-error heat and material balances and vapor-liquid equilibrium computations. However, since the tray efficiencies are often only approximately known, the designer frequently employs short-cut methods based on the required separation of key components. Such methods include the Kremser method (*23*) for absorption column calculations. For distillation columns the Colburn method (*8*) for determining minimum reflux ratio coupled with Fenske's equation (*14*) for minimum stages at total reflux and the chart of Martin and Brown (*28*) for determining the theoretical stages required at a practical reflux ratio is frequently used.

To determine the actual physical plates required in a column, the theoretical stages must be divided by a tray efficiency. Here the published information is almost nonexistent. The work of Linde (*26*) has already been mentioned. He used a single 8-in. diam. sieve-plate with radial liquid flow having 0.9 mm. perforations on 3.2-mm. triangular centers. Murphree vapor efficiencies varied between 70 and 100%, being greatest at concentrations where foaming was observed. The



▲ Fig. 4. Typical bubble-cap tray for air separation column.

▲ Fig. 5. Assembly of bubble-cap column for air separation plant.

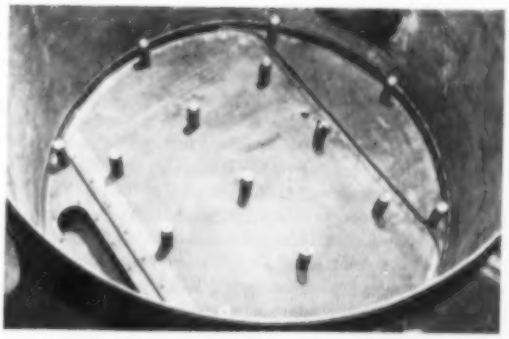


Fig. 6. Sieve plate during assembly into column shell N_2 scrub column for ammonia synthesis gas purification.

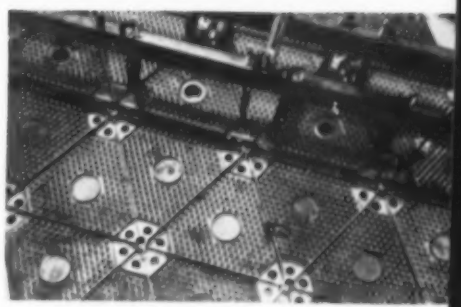


Fig. 8. Segmented bubble-cap tray, 180 ton/day O_2/N_2 generator.

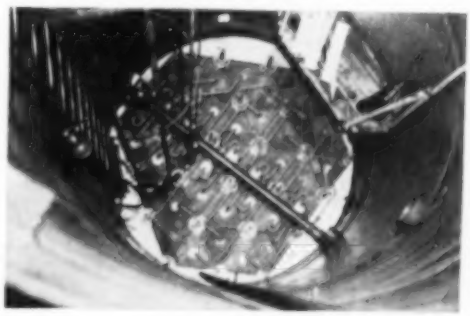


Fig. 9. Top plate of segmented bubble-cap column showing reflux header.

Fig. 10. Condenser-reboiler for use in segmented bubble plate column.

efficiency increased at higher throughput and higher pressure, but these appeared to be minor effects. Augood and Sellers (*32*) report the results of H_2-HD and O_2-N_2 separations using a 27-mm. diam. glass column with a single bubble cap on each tray. For the O_2-N_2 system Murphree plate efficiencies varied from 87 to 63% as the oxygen concentration changed from dilute to 93-98% with an over-all efficiency of 76% for a liquid seal of 1.4-2.6 cm. With a 2.5-3.5 cm. liquid seal, efficiencies were about 5% higher. For the HD-H_2 system Murphree plate efficiencies of 45-50% were reported.

Aside from these results the designer must rely on previous experience and inferences drawn from high-temperature distillation in order to select a realistic tray efficiency. Years of designing, constructing, and perhaps operating low-temperature-distillation equipment have given the designer the background he relies on most heavily in selecting tray efficiencies. Usually this experience comes from knowing that an air-separation plant in which 65% tray efficiencies were used for design purposes operated satisfactorily. It may come also from taking comprehensive operating data on commercial-sized plants. Such data, however, are not readily obtained since the equipment is compactly built and immersed in insulation so that additional sample cocks and thermocouples cannot be installed easily.

Accurate vapor-liquid equilibrium data for the system and conditions at hand are basic to any calculation method. The availability of these data for low-temperature systems varies markedly with the system. The most heavily investigated system is that of O_2-N_2-A. Here data on all the binary pairs have been obtained throughout the pressure range of general interest.

On the ternary system, data are available only at 1,000 mm. Hg total pressure (*37*). The oxygen-nitrogen system has been investigated by Dodge & Dunbar (*11*), by Armstrong, Goldstein, and Roberts (*1*), and by Inglis (*21*). These data cover the pressure range from .3 lb./sq.in.abs. (65° K.) to 490 lb./sq.in.abs. (125° K.) and are consistent. The argon-nitrogen system has been studied by Holst and Hamburger (*20*), and Fastovskii and Petrovskii (*12*). Here the data cover the pressure range from 10 to 100 lb./sq.in. abs. The argon-oxygen system has been studied by Bourbo and Ishkin (*6*), Inglis (*21*), Fastovskii and Petrovskii (*12*), and Clark, Din, and Robb (*7*). These data cover a pressure range from 10 to 100 lb./sq.in.abs. Recently Latimer (*24*) has shown that all these systems behave like regular solutions (*19*), that is, solutions in which the entropy of mixing is the same as for ideal liquid solutions.

Equations were written expressing the relative volatilities for the binary pairs in terms of concentration and temperature. Of the available data only that of Clark, Din, and Robb (*7*) disagreed with these equations. These were combined to give equations for the volatilities of these pairs of components in the ternary system. Results agreed with the data of Weishaupt (*37*) for the ternary system at 1,000 mm. Hg. No other data were available against which to check the equations. This correlation gives the design engineer a complete and internally consistent set of vapor-liquid equilibrium data for the O_2-N_2-A system. Further experimental work on the O_2-A system and on the ternary system at higher pressure will be necessary to substantiate these results.

Data on systems containing only light hydrocarbons are available for many two-component and for a few three-component systems. Katz and Rzasa (*22*) list this work published before 1945. More recent bibliographies are those given by Hadden (*18*) and by DePriester (*10*).

Typical of such data are those for the CH_4-C_2H_4 system, a correlation being given in Figure 11. This is based on the work of Guter, Newitt, and Ruheman (*17*) and of Volova (*36*) which adequately covers the pressure range from 100 to 1,000 lb./sq.in.abs. At temperatures above −100° F. the data of Volova appear to be unreliable and that of Guter *et al* were used exclusively.

Data on systems of more than two components are scattered and fragmentary, and generally are unavailable in the low-temperature range. In fact DePriester (*10*) finding no ternary data in the +100 to −100° F. range took such data in order to check his *K*-value correlation.

At higher temperatures the properties of light hydrocarbons have been found to obey the principle of corresponding states and to be reproduced with a high degree of precision by equations of state such as the Benedict-Webb-Rubin (*3*) equation. These equations for pure components have been combined to give relations for multicomponent mixtures. From these, figures have been prepared which allow *K*-values to be calculated once the molal-average-boiling points for both liquid and vapor phase have been established. As originally published (*4*) each pair of figures applied to a single compound at a single pressure. DePriester (*10*) has since published simplified figures, a pair applying to a single compound at pressures from 14.7 to 1,000 lb./sq.in.abs. and temperatures from −100 to 400° F. His claimed *K*-value average absolute deviation of 6.4% is equal to that claimed for the original figures. However, this temperature range is still not great enough for the low-temperature process designer, and he must fall back on the law of corresponding states, perhaps as improved by Lydersen, Greenkorn, and Hougen (*27*) for a generalized treatment applicable to the low-temperature range.

Present-day low-temperature processes tend toward those involving mix-

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tures of hydrocarbons and nonhydrocarbons. Examples include ammonia-synthesis gas production from natural gas, from petroleum partial oxidation and reformer gas, or from coke-oven gas. In these processes H_2, N_2, CO, A, and CH_4 will be present as well as higher hydrocarbons. Vapor-liquid equilibrium data are scattered and contradictory, while the generalized approaches, either through equations of state (*9*) or the law of corresponding states have been unsuccessful. The H_2-N_2-CO system has been studied by Verschoyle (*35*), by Ruhemann and Zinn (*31*), and by Fischer (*15*). The H_2-N_2-CH_4 system behavior was studied by Steckel and Zinn (*33*). In both these systems the data are contradictory and incomplete.

Systems containing H_2 with hydrocarbons have been studied by Aroyan and Katz (*2*), who investigated the H_2-C_4H_{10} system, by Williams (*38*), who studied the H_2-C_2H_4, H_2-C_2H_6, H_2-C_3H_6, H_2-C_3H_8 systems, and by Benham (*5*), Steckel and Zinn (*33*), Freeth and Verschoyle (*16*), Fastowsky and Gonikberg (*13*), and Levitskaya (*25*), who studied the H_2-CH_4 system. Williams (*38*) gives a correlation for H_2 K-values in these systems as a function of temperature and concentration, but this correlation is unsatisfactory for the H_2-CH_4 system. In all these systems the hydrogen shows a reverse solubility over much of the two-phase range, that is, increased temperature at constant pressure results in an increased H_2 solubility.

The H_2-CH_4 data for the $-297°$ F. isotherm are shown in Figure 12 as an example of the scatter sometimes found in these data. This isotherm is just above the point of solid CH_4 formation, and since the CH_4 concentration in the liquid is low the analytical difficulties are increased. Experience in the performance of plant units processing these components has indicated that the data of Fastowsky and Gonikberg (*13*) are incorrect. A correlation of the data available for this system is shown in Figure 13. As is typical in many such systems, data are available only above 400 lb./sq.in.abs. Below this pressure the curves have been extrapolated, with CH_4 K-values approaching 1.0 as the CH_4 vapor pressure is approached. This lack of data occurs at the very pressure range of most interest to industrial process designers. It undoubtedly stems from the increased difficulty of analyzing components present at low concentration and the belief that at lower pressures the mixture can be represented satisfactorily by ideal solution laws.

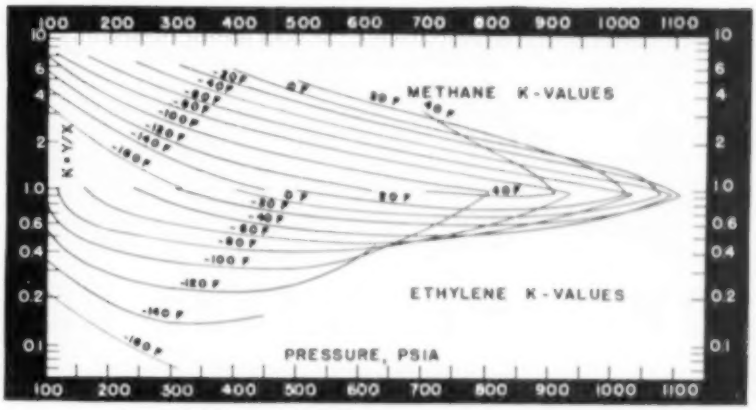

Fig. 11. Methane-ethylene system vapor-liquid equilibria.

Acknowledgment

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Fig. 12. Hydrogen-methane vapor-liquid equilibrium data, —297° F. isotherm.

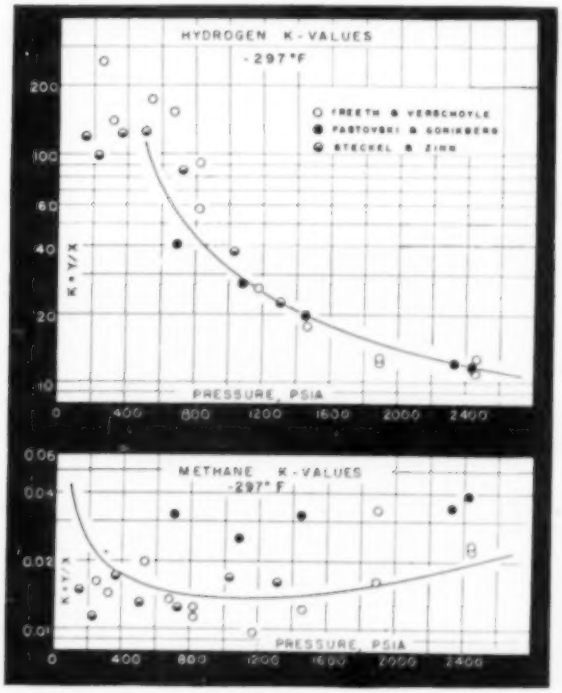
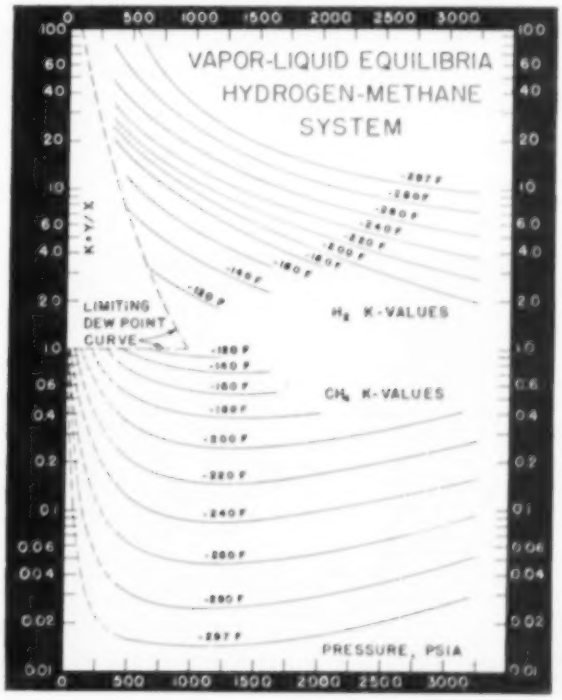


Fig. 13. Hydrogen-methane system vapor-liquid equilibria.



Special features and applications of various heat exchange methods used in the low-temperature field and of several heat-exchanger types and heat regenerators are described in the accompanying paper. The relative merits of freeze-out exchangers, reversing heat exchangers, and regenerators are discussed. An approach to the economic sizing of heat exchangers is also given.

LOW TEMPERATURE HEAT EXCHANGE

William E. Gifford | Arthur D. Little, Inc., Cambridge, Massachusetts

In any low-temperature process plant, most of the refrigeration is supplied by the exhausting gases warming to room temperature in highly efficient heat exchangers. An expansion engine used in an air-distillation plant may drop the temperature of the gas passing through it from 160 to 80° K., thus providing refrigeration through a range of 80 degrees. The heat exchanger, however, has to cool the same gas from 300 (room temperature) to 160° K. before the gas enters the expansion engine, a temperature change of 140° K. In addition, only part of the total gas-flow actually passes through the expander. Refrigeration to this other portion is supplied by exhausting gases warming to room temperature.

In a helium liquefier, the effect is greater. The gas, in passing through one of the expanders of a two-engine helium liquefier, is cooled only 10° K., but it is cooled 280° in heat exchangers before it enters the expander.

Without the use of heat exchangers, expanders in an air-liquefaction process could produce temperatures down to only about 150° K., far from the air liquefaction point of 85° K. The Joule-Thomson system would give a temperature decrease of only 25 to 30 degrees.

In any chemical process plant, the use of efficient heat exchangers can effect large savings in heat or power requirements. In low-temperature work, they are an absolute necessity without which the process would be impossible.

In any operation where the gas returning to the compressors or exhausting to the atmosphere is colder than the entering gases, refrigeration is being lost. This loss must be made up by the refrigerating means available. Since no heat exchanger will be perfectly efficient, some refrigeration will always be lost in this way and the amount Q_R will be given by:

$$Q_R = mC_p\Delta T$$

where

m = mass flow of gas
C_p = specific heat
ΔT = temperature difference between the entering and exhausting gases.

This Q_R gives the amount of heat that must be removed because of heat-exchanger inefficiency. In a gaseous oxygen plant, the power required for the refrigeration to overcome this loss is the largest single production cost item. Therefore, it needs careful attention.

Refrigeration (the extraction of heat) is accomplished by means of the compression of gases. This is true no matter what refrigeration system is used, whether it be vapor cycles, expansion engines, or even a Joule-Thomson process. At lower and lower temperatures, refrigeration becomes increasingly costly in compressive work. Therefore, it is necessary to achieve a smaller and smaller temperature difference between the exhausting and en-

Fig. 1. Hampson coil-type heat exchanger.

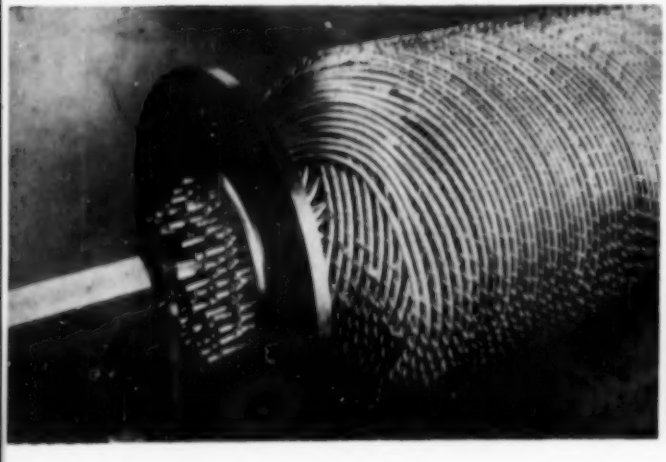
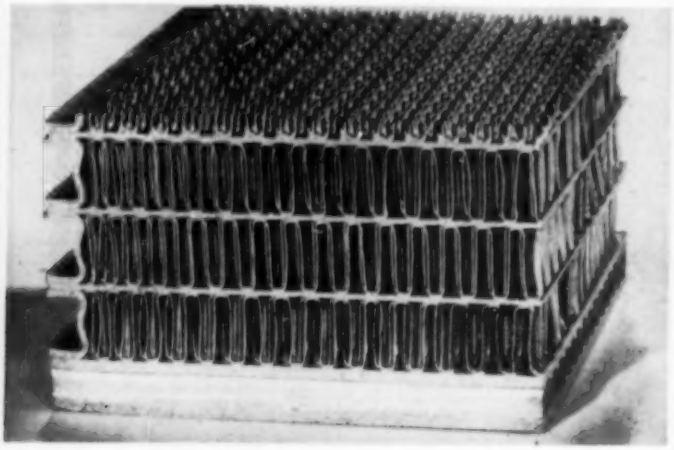


Fig. 5. Cross-sectional view of Trane heat exchanger.



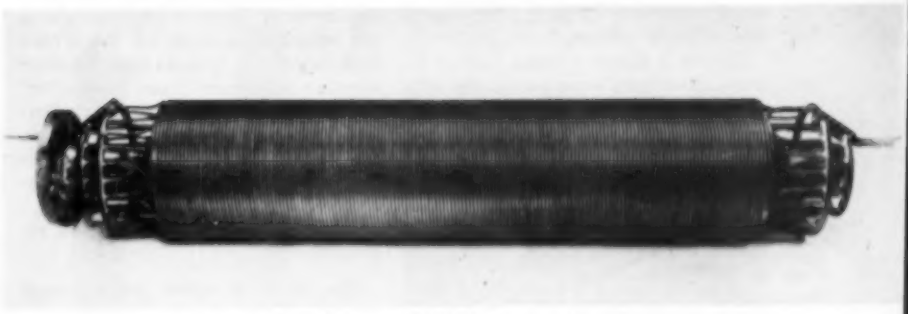


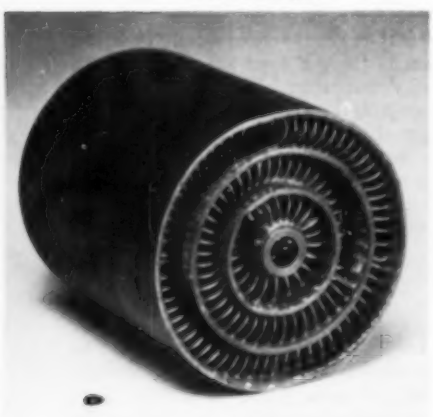
Fig. 2. Heat exchanger used in hydrogen liquefier.

tering gas streams. Because of the wider temperature range over which the heat exchanger is operating, it becomes more difficult to achieve even the same temperature difference as would be achieved in a heat exchanger used near room temperature.

Consequently, there is a demand for the development of better heat-exchanger types. The old shell-and-tube-type heat exchanger is not suitable for producing temperature differences of a few degrees in these applications. This system can be improved somewhat by the addition of finned tubes and many baffles, but this becomes expensive and is not particularly satisfactory.

Typically in a low-temperature process, the temperature difference between the two gas streams entering a heat exchanger will be of the order of 200° K. The temperature difference between the exhausting gas and entering gas in parallel-flow or crossflow heat exchangers will be of the order of 30 to 70% of the above 200° K.

Fig. 3. Cross section of Collins tube heat exchanger.



depending on the relative heat capacities of the two gas streams. This would give exhausting gas temperatures 50 to 150° C. below room temperature. Such practice would be intolerable in low-temperature process work. The refrigeration loss would be definitely prohibitive. As a result, parallel-flow and crossflow heat exchangers are not used and essentially all gas-to-gas heat exchangers are effectively counterflow heat exchangers.

Design Problem

There are four principal problems in the design of a highly efficient heat exchanger:

1. A large amount of surface area must be packed into a small volume.
2. The path through which the heat must flow through metal in passing from one gas stream to the other must have small thermal resistance so that no appreciable temperature gradient is required. Effectively, this means that the distance between any part of either of the two counterflowing gas streams must be within a few tenths of an inch of the other stream. For large heat exchangers this involves complicated manifolding problems.
3. The flow through all sections of the heat exchanger must be nearly equal since, if a large part of the flow were to channel through one section of the heat exchanger, a large part of the surface area might be useless. Also, much of the warming gas may not have access to the gas being cooled.
4. The pressure drop through the heat exchanger must be made as small as possible.

In typical low-temperature plant heat exchangers, the entering high-pressure gas is being cooled by an exhausting low-pressure gas since the gas expansion is used to produce refrigeration in either an expansion engine, a vapor cycle, or a Joule-Thomson process. Figure 1 is a picture of an old Hampson coil-type heat exchanger. Heat exchangers of this type have been used in low-temperature plants for years.

The heat exchanger consists of a bundle of tubes wrapped on a mandrel. The high-pressure gas passes through the inside of tubes in a spiral course down through the tube bundle. The low-pressure gas passes up parallel to the axis of the tube bundle, which is held in a cylindrical tank case. The tubes must be equally spaced so that the gas flow will not channel. The method of doing this generally involves an unusual technique that must be carefully followed in the winding. In this case, the spacing is accomplished by means of a wire spirally wrapped around each tube.

Figure 2 is another example of this type of heat exchanger used in the National Bureau of Standards hydrogen liquefier at Boulder, Colorado. It can be noted how closely and evenly spaced the tubing is. Again, high-pressure gas flows through the inside of the tubes and low-pressure gas flows outside the tubes parallel to the axis of the bundle. It is possible with this type of heat exchanger to achieve temperature differences between two gas streams of only 3 to 10° K. when gas is cooled from room temperature to the boiling point of liquid nitrogen, 80° K., a temperature change of 220 degrees. This type of heat exchanger is most applicable where there is a great difference in the pressure of the two gas streams. The gas-flow area inside the tubes is far less than that outside the tubes, and the path length is far greater—perhaps in the ratio of 10 or 20 to 1. If the pressure is much greater for the inflowing stream, however, the pressure drop may be only the same fraction of the total pressure in both gas streams. Such heat exchangers are most useful in high-pressure systems and are still used in many small-capacity liquid-air distillation plants.

Figures 3, 4, and 5 show some

examples of more modern heat exchangers. These all pack a large area into a small volume.

Figure 3 shows a cross section of the Collins tube heat exchanger (*1*) manufactured by Joy Manufacturing Company.

It is made of concentric tubes filled with a packing soldered to the walls to give added surface. The packing is a spiral flattened wire. The packing also increases the pressure drop.

The net result is an increased heat transfer far outweighing the detrimental effect of increased pressure drop. The counterflowing gases pass through alternate concentric tube passages.

In Figure 4 is shown the component parts of another high-efficiency heat exchanger, the McMahon perforated-plate heat exchanger (*2*) developed at Arthur D. Little, Inc.

This heat exchanger is composed of a stack *D* of perforated plates, *A* and *C* separated by gaskets *B*. The counterflowing gas streams are kept separate from each other by the gasket in alternate rectangular passages in *D*. The plates are a good conductor. Heat flows through the plates between the passages although the gas cannot. Heat flows poorly end to end since the gaskets are poor conductors. An actual heat exchanger would consist of a stack of plates and gaskets 3 to 10 ft. long, held together under appreciable compressive force.

In Figure 5 is shown a cross-sectional view of a typical Trane heat exchanger (*4*) made by the Trane Company.

The counterflowing gases pass in opposite directions in alternate strip sections of the heat exchanger. Different types of finning are available giving a variety of surface areas per unit volume and of pressure drops per unit length. Surface areas as high as 500 sq. ft./cu. ft. are available. These heat exchangers are made of brazed aluminum. They are usable up to pressures of 600 lb./sq. in. and have been utilized widely in low-temperature process work.

The extended-surface heat exchangers described by no means cover every type available but are presented to give a general idea of what has been done. With heat exchangers of these types, one can obtain temperature differences of a few degrees when operating over a temperature range of several hundred degrees with surprisingly small volume. Typically, these extended-surface heat exchangers are expensive. Costs may be as high as $500/cu. ft. However, a cubic foot will contain 300 to 500 sq. ft. of surface and the resulting saving in refrigeration costs will justify the construction cost.

Heat exchangers are complicated in construction. Many segments such as the separate passages of the Trane heat exchanger have to be built close together but sealed from each other. A regenerator set, with a wide application in low-temperature process work, replaces the heat exchanger and requires none of its complexity of manufacture.

In Figure 6 is shown such a regenerator set.

The gas to be cooled passes through one cylinder and is cooled by a packing material which is slightly heated in the operation. The exhausting gas passes through the other cylinder and is heated back to room temperature by contact with the packing which is cooled slightly in the operation. The packing material may be simply small iron, steel, or aluminum balls, corrugated metal, or even uniform-sized pebbles. It is best if the surface area is large per unit volume to give good heat transfer, and if the heat capacity per unit volume is large so that the temperature of the packing changes as little as possible.

After a short period of time, the flow of gases is switched between the two cylinders. The packing that was being heated in cylinder No. 1 is then cooled as it heats the exhausting gas, and the packing in cylinder No. 2 that was being cooled is now heated as the entering gas is cooled. By fairly rapid switching one may keep the temperature of the packing from changing by more than a few degrees.

The net effect of the set of reversing regenerators with automatic switching valves is exactly equivalent to that of a heat exchanger. The entering and exhausting gases are near to each other in time in the same position, rather than in space at the same time.

Regenerators—Advantages, Disadvantages

It is obvious that a regenerator will be less costly than the highly efficient heat exchangers referred to. A tankful of pebbles is certainly easier to make than the extended-surface packed heat exchangers. Reliable, rapidly acting but tight-switching valves may be fairly costly however. Regenerators, therefore, are used only in rather large applications where the valve cost may be allowable.

Nevertheless, there are disadvantages to regenerators. When gas flow is switched from one cylinder to the other (it will occur every 30 sec. to several minutes), the pressure in the higher pressure stream must be lost and the contained gas recycled. This involves a significant power loss if the pressure is rather high. As a result, regenerators are most applicable where the difference in gas pressure is small. They are rarely used where pressure differences are large.

In addition, regenerators give a certain amount of mixing of the entering and exhausting gas streams and, as a result, contaminate the gas product. This limits the application of regenerators. Most of them are used in large-scale, low-pressure, low-purity plant applications.

Regenerators may be designed to give temperature differences of only a few degrees in almost any application.

It was stated previously that heat exchangers supply more refrigeration than the refrigerating machines. Also, they can do a large part of the purification job when the impurity level is quite low.

As the gas passes through the heat exchanger, the temperature of the gas goes below the vapor pressure of the impurities and they start liquefying or freezing out on the surfaces of the heat exchanger. Arrangements can be made to remove the collected impurities in several ways. Two parallel heat exchangers may be used so that one may operate while the impurities are removed from the other.

Reversing Heat Exchangers

Another method is to reverse at various time intervals the channels used by entering and exhausting gas streams. In this way impurities from the entering gas stream are deposited for a period and then the impurities are picked up in the exhausting gas stream while impurities are being deposited in the other flow channel of the heat exchanger. These are well known as reversing heat exchangers. Such a method could be used only in a system where it is permissible to have the impurities back in the exhausting gas stream. This might occur in an air-distillation oxygen plant where the impurities could be permitted in the exhausting nitrogen.

In regenerators, the frequency of reversal is determined by the heat transfer requirement rather than impurity-removal requirement. Thus impurity removal is an automatic feature of regenerators. This may be a disadvantage if impurities must be kept out of the exhausting gas. Recent developments may make it possible to get around this difficulty by the use of a hybrid unit which is a combination of heat exchanger and regenerator.

Care must be taken not to overemphasize small temperature differences in heat exchangers. Emphasis is important, but it can be overdone. A study should be made in each case to determine the approximate heat-exchanger area to use. The more heat-exchanger area used, the smaller the temperature difference will be, and

the less the refrigeration will cost. Increased area, however, will involve increased cost; and the principal object in any process plant is minimum total cost.

The cost picture for some hypothetical heat-exchanger problems is shown in Figure 7 where heat-exchanger and refrigeration costs, because of heat exchanger inefficiency, are plotted vs. area. The exchanger costs are plotted as directly proportional to area and the refrigeration costs are plotted as some inverse function of area. It is apparent from the total-cost curve that there is an optimum amount of heat exchanger to use and that missing this optimum by a significant margin may be costly. It might be expensive to miss it in either direction. The optimum may vary considerably with factors like temperature, relative heat capacities of the two gas streams, the particular-type heat exchanger being used, expected life of plant, etc. Such problems require careful study. This subject is treated in more detail (*3*).

In summary, low-temperature processing is made possible principally by the skillful use of high-efficiency heat exchangers. In planning a low-temperature process, one must view heat-transfer problems in a quite different way from what the practice in more typical chemical-plant work has been. Loss of refrigeration represented by a temperature difference between two gas streams of more than a few degrees Fahrenheit must be considered undesirable.

There are a number of types of modern high-efficiency heat exchangers and heat-exchange methods that can make small refrigeration losses possible. When one studies the performance of some of this equipment, it becomes surprising to find how easy it is to conserve heat and refrigeration. Study of low-temperature processing-heat-exchange methods may lead to better heat-exchange procedures in general chemical-plant work.

Fig. 6. Regenerator.

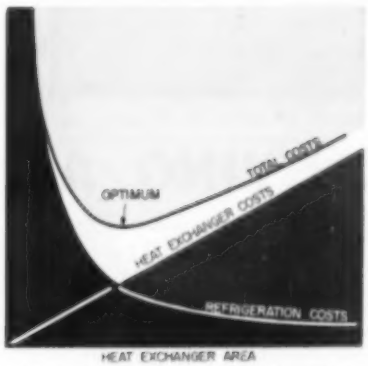


Fig. 7. Heat exchanger and refrigeration costs vs. area.

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2. Fisher, A. W., Jr., and R. J. Bowen, *Chem. Eng. Progr.*, **45**, No. 6, p. 359-69 (June, 1949).
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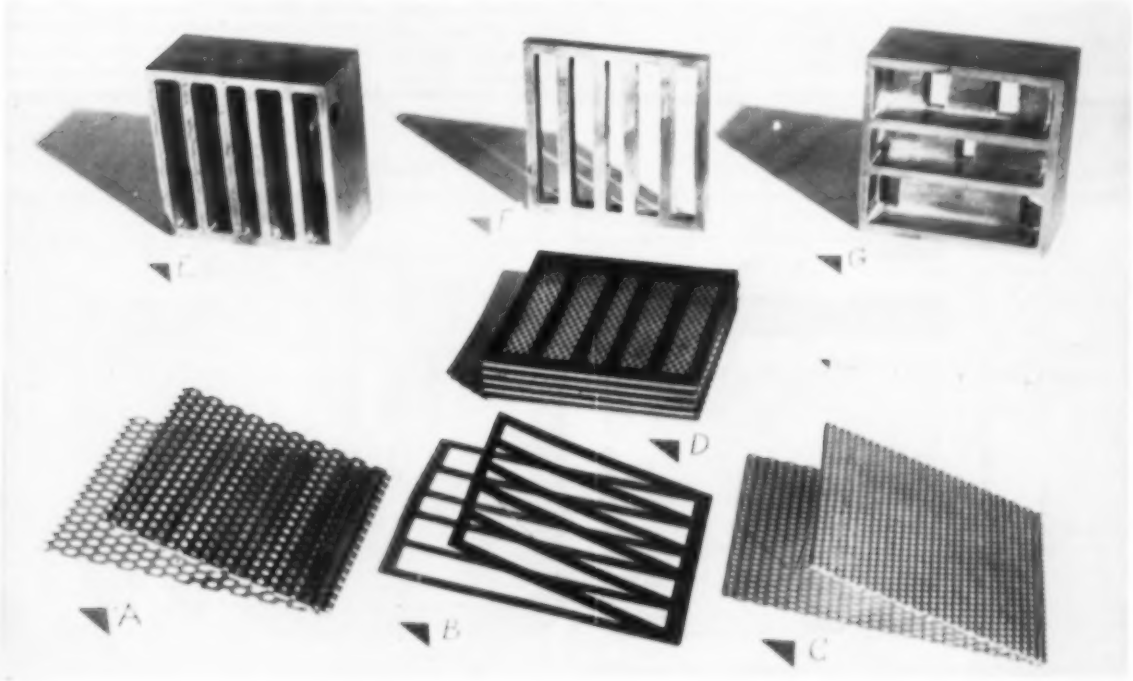
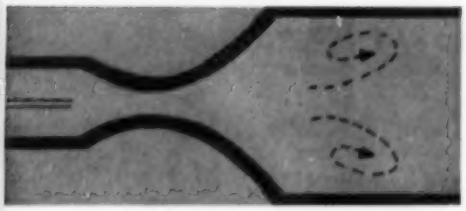
Fig. 4. Components of McMahon perforated-plate heat exchanger.





DRYING AQUEOUS SODIUM SULFATE IN THE JET SPRAY DRYER

Last month in CEP authors Comings and Coldren described the design of an unusual spray dryer and explained the details of its operation. This article is an account of the application of an improved model to the drying of a sodium sulfate solution.

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Development of the jet spray dryer has been described by Coldren and Comings (*11*) as a modification of the high-velocity vaporizer (*12*). The dryer discussed in this article is an improved model which provides for more uniform operation over wider ranges of temperature and air-flow rates. It has been used to dry sodium-sulfate solution, a suspension of *Serratia marcescens* which is a bacterium (*11a*), milk, and eggs. The jet spray dryer produces solid spherical particles about 5-μ diam. These have been dried rapidly in from 3 to 30 millisec. The air-flow pattern and the path of the individual particles are known and subject to control so that no particle is subjected to reheating in the hot drying zone. Because of these unique features the jet spray dryer processes heat-sensitive material without damage.

Wall deposition of the product is not a problem under the proper operating conditions. High primary-air temperatures and high feed rates have been found to be desirable. An amount of unheated secondary air about ten times the primary air is required as entraining air for the primary-air jet. In a series of runs made with a solution of sodium sulfate most of the drying took place in the primary air. If the temperature at the lower end of the drying tube was much less than that of the secondary air, the drying of the sprayed droplets was incomplete under the operating conditions employed.

The dried sodium-sulfate product was composed of fine, spherical, solid particles, and its moisture content was almost always less than one per cent. The mass particle-size distribution of the dried product was found to follow the log-normal-distribution function. The geometric-mass-mean diameters for particles varied from 3.2 to 4.4 μ and the geometric standard deviations were approximately 1.5. Volume-to-surface-mean diameters of the product were determined from these two parameters. Predicted volume-to-surface-mean diameters were also calculated

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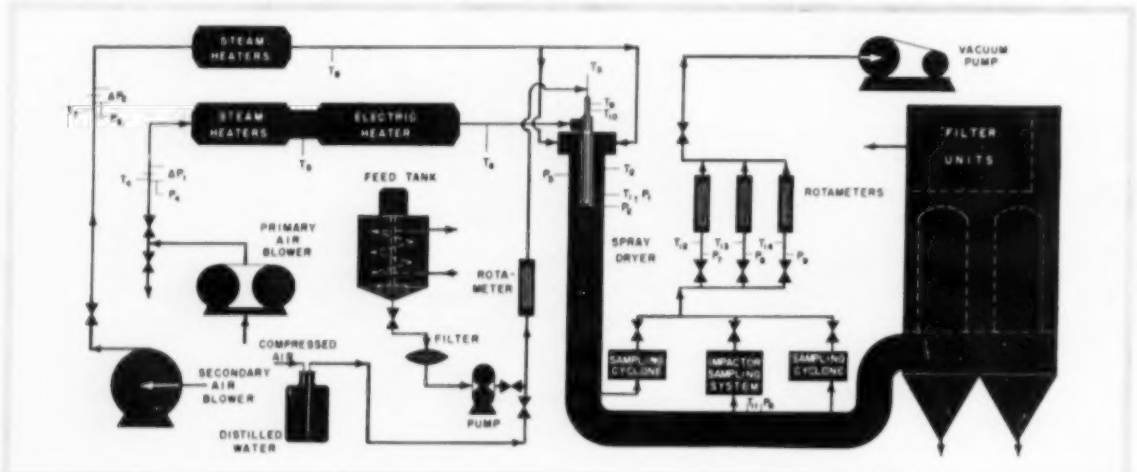
Fig. 1. High velocity spray dryer.



from the Nukiyama and Tanasawa equation and a material balance. The measured and predicted diameters of the dried particles were found to be in good agreement. Results from the analysis of variance of the geometric-mean diameter further confirmed the effectiveness of the Nukiyama and Tanasawa equation (*29*) and a material balance for the prediction of the size of the sodium-sulfate product.

The heat requirements under the more satisfactory operating conditions exceed those of conventional spray dryers by a moderate amount. Power costs are considerably higher. However applications to biological and food products such as milk may be worthwhile if superior product quality is of primary importance.

Experimental

A schematic diagram of the equipment is shown in Figure 1, and a photograph is shown in Figure 2.

A 300-cu. ft./min. Roots-Connersville cycloidal blower supplied the primary air at 15 lb./sq. in. gauge. The secondary air at 2 lb./sq. in. gauge was provided by a 1,400 cu. ft./min. North American turboblower. Aerofin steam heaters and a 25.5 kva. electric-resistance heater were used to heat the primary air to temperatures up to 700° F.

Details of the jet spray dryer are shown in Figure 3.

The drying unit consisted of a primary-air tube, a liquid-injector assembly, a secondary-air annulus, and a drying tube. The primary air entered at the top of the dryer and passed down through a brass pipe to a stainless-steel nozzle. The nozzle was a standard A.S.M.E. long-radius, low-ratio nozzle (*4*) with a 0.65-in. throat diameter. Pressure taps and copper-constantan thermocouples were installed in the primary-air tube and nozzle as shown in Figure 3. The secondary air enters through two 6-in. ducts near the top of the dryer and flows through an annulus parallel to the primary air as shown in Figure 1.

The liquid solution or suspension to be dried is injected into the hot primary-air stream at the throat of the nozzle entering through a water-jacketed liquid-injector assembly shown in Figure 4. Atomization and the drying action start at this point. The tip of the liquid-injector assembly was located ¼-in. back from the primary-air-nozzle exit. A copper-constantan thermocouple encased in 16-gauge hypodermic tubing was inserted in the liquid-feed-injector tube so that the junction of the thermocouple was within 1 in. of the liquid-feed-nozzle outlet. The liquid-feed temperature was measured with this thermocouple.

Primary air and the atomized particles surrounded by the secondary air flow into a stainless-steel drying tube.

This tube is 8 in. in diam. and 6 ft. long. The primary air and the atomized particles form a jet which behaves similarly to a free jet or rather to a jet in a duct (*1, 3, 37*). Drying takes place rapidly in the jet as it spreads out and is essentially complete by the time the jet reaches the drying-tube walls. This occurs in about 17 to 21 in. In the remaining length of drying tube the drying is completed and the primary air, the secondary air, and the dried particles are thoroughly mixed.

After drying, the air suspension of the dried material passes from the drying tube through an 8-in. stainless-steel duct about 10 ft. long to the collection system shown in Figures 1 and 2. The collection system consisted of Orlon bags followed in series by deep-bed fiber filters. This system was designed primarily for cleaning the exit-air stream and not for the recovery of the dried product.

The liquid feed was stored in a 25-gal. stainless-steel tank. The feed was pumped through a Sprinkman filter (containing a cotton gauze pad), and then through a rotameter to the liquid-injector assembly by a Zenith 2QE metering unit equipped with a Type BC-4605 stainless-steel gear pump.

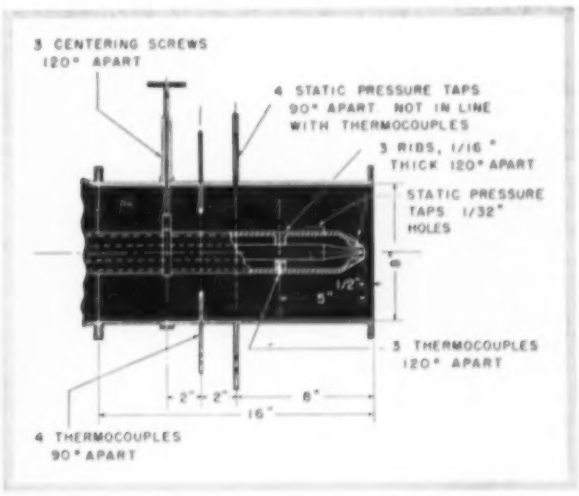
Samples for moisture determination were drawn from the air stream through 1-in. I.D. glass cyclones by a large vacuum pump. Two cyclones were operated simultaneously, one located 65 in. downstream from the primary-air nozzle and the other at the inlet to the collection system. The samples were drawn into the glass cyclones from the air stream through probes made from 16-gauge ¼-in. O.D. stainless-steel tubing. Dried powder from the glass cyclones was collected in glass test tubes.

Temperature profiles were measured with a bare copper-constantan thermocouple. This thermocouple protuded from a ¼-in. stainless-steel thick-walled tube which was mounted on a traversing mechanism. Temperature traverses were taken at seven positions along the drying tube beginning at 6.5 in. from the nozzle.

Two to three hours were usually required to reach steady-state operation and during this time the temperatures and air rates were adjusted to the desired values. Before starting to dry, distilled water was fed first to the dryer for about 10 min. at the same rate as planned for the liquid solution or suspension. The liquid solution or suspension was then switched to the dryer without any interruption in the liquid flow. The cyclones collected samples for about 1 hr. and this mate-

Fig. 2. Photograph of the spray dryer equipment.

Fig. 3. Approach section of the dryer.


3 CENTERING SCREWS 120° APART
4 STATIC PRESSURE TAPS 90° APART NOT IN LINE WITH THERMOCOUPLES
3 RIBS, 1/16" THICK 120° APART
STATIC PRESSURE TAPS 1/32" HOLES
5" 1/2"
3 THERMOCOUPLES 120° APART
2" 2" 8"
16"
4 THERMOCOUPLES 90° APART

rial was analyzed for moisture content by drying a sample to a constant weight at 110° C. The dryer was partially disassembled, washed clean, and assembled after each run.

Results

Table 1 shows the significant runs with the use of 5% aqueous sodium-sulfate solution. The secondary-air rate for these runs was approximately 5,000 lb./hr. No deposition was ever found around the primary-air nozzle. Wall deposition is classified from very small to considerable, and the distance downstream from the nozzle for the first trace of deposition to appear on the drying-tube wall is called the initial light deposition. The distance downstream from the primary-air nozzle where initial uniform deposition became more noticeable is indicated and the thickness of the deposition at this point is called the thickness at the uniform part. This deposition was uniform with no noticeable excessive deposition on one side of the drying tube such as was reported by Comings and Coldren (*11*). The thickness of this uniform part was constant in the drying tube for a length of 4 to 5 in. This deposition thickness then usually tapered down along the rest of the length of the drying tube, and the measurements of this thickness at the lower end of the tube are called the deposition thickness at the end of the drying tube. Outlet-air temperatures were measured in the bare-thermocouple traverse at 65 in. from the nozzle.

The initial wall deposition given in Table 1 corresponds to an angle of spread of the atomized spray of from 17 to 25°. Elgert (*15*) noted that the secondary- to primary-air ratio exerted an important influence on the wall deposition, and he recommended a ratio of at least 10 to eliminate wall deposition. It was found here that high secondary- to primary-air ratios eliminated the wall deposition when other conditions were favorable. Deposition began to be appreciable for the runs with 350° F. primary air, but with 450 and 550° F. primary air there was only a small amount of solid deposited on the wall and this was 1/16 in. or less thick. Secondary-air temperatures may be low, and satisfactory heat economy may be obtained with a high ratio of secondary to primary air.

The thermocouple traverse at 6.5 in. showed a peak about ¾ in. from the center line due to the high temperature of the primary air and indicated that the wet spray had not reached the periphery of the primary-air jet at this section. When the wet spray comes in contact with the thermocouple probe, the probe remains wet and the wet-bulb temperature of the air is measured. This is not the exact wet-bulb temperature due to the use of saturated sodium-sulfate solution (*25*) instead of water on the thermocouple. At 19.5 and 26 in. the primary-air jet has reached the wall. This agrees with the calculations which follow. At 52 in., nearly all the sprayed material was completely dry by the time it reached this point. The temperature profiles near the nozzle are unsymmetrical for all the runs with this spray dryer (*27, 31*). Klar (*23*) found that the inlet secondary-air velocity was not uniform, but that the velocity was somewhat greater on one side of the center line.

The heat added per pound of drying air for the sodium-sulfate runs is shown in Table 2. The combination of a high-temperature primary-air stream, a high rate of feed, and an unheated secondary-air stream gives the desirable combination of satisfactory operation and lower heat requirements.

The moisture content of the dried sodium-sulfate product collected by the sampling cyclone was less than 1% for almost every run. These measurements did not show any trend although the cyclone samples from runs with incomplete drying may not be representative because of the deposition of undried product in the sampling probe. In the majority of cases, the moisture content of the sample collected by the cyclone further downstream was slightly less than that collected by the upstream cyclone. This is to be expected as these particles were exposed to drying for longer periods of time.

Table 1.

Secondary-air temperature °F.	cor. as.	Liquid feed temp. °F.	Primary air rate lb./hr.	Nature of deposition *	Initial light deposition in.	Initial uniform deposition in.	Deposition thickness at uniform part in.	Deposition thickness at end of drying tube in.	Running time of feed hr.	Outlet temperature °F.
Primary-air temperature, 350° F. Feed rate 2.0 gal./hr.										
	107	114	400	M	18	21	1/16	1/16	2	130
125	92	75	450	M	19½	22	3/32	1/64	3.25	120
	75	84	500	C	17	...	1/4	1/32	2.50	124
	78	70	400	M	19½	...	1/10	1/64	2.67	161
175	109	119	450	S	17	20	1/16	1/64	3.00	163
	98	138	500	VS	18	21	1/32	1/64	3.58	176
Primary-air temperature, 350° F. Feed rate 3.0 gal./hr.										
	73	83	400	C	20	25	1/4	3/8	3.17	97
125	97	103	450	MH	18	20	1/8	1/16	2.40	110
	112	105	500	M	16½	16½	1/10	1/64	2.83	121
	108	107	400	M	...	21	1/16	1/32	2.75	160
175	85	76	450	———	———	not recorded	———	———	3.58	183
	111	108	500	M	19	...	3/32	1/32	3.08	171
Primary-air temperature, 450° F. Feed rate 2.0 gal./hr.										
	83	99	400	S	19	21	1/16	1/16	3.33	133
125	110	138	450	S	17	...	1/16	1/64	2.67	136
	68	105	500	S	17	19	1/16	1/64	4.42	136
	99		400	———	Pump trouble, water used intermittently	———	———	———	3.42	178
175	73	81	450	S	19	24	1/32	1/64	4.42	183
	113	134	500	VS	17	...	1/32	Negl.	3.75	197
Primary-air temperature, 450° F. Feed rate 3.0 gal./hr.										
	106	104	400	M	17	20	3/16	1/64	2.33	121
125	83	99	450	S	18½	22	1/10	1/32	3.25	133
	108	125	500	M	17½	21	1/32	1/64	2.42	129
	79	71	400	M	19	23	3/20	1/32	3.67	170
175	101	97	450	S	18	...	1/16	1/64	2.70	176
	91	82	500	S	18	20	3/64	1/64	3.17	180
Primary-air temperature, 550° F. Feed rate 2.0 gal./hr.										
	96	140	400	S	19	21	1/16	1/64	2.75	140
125	90	153	450	S	19	20	1/32	1/64	2.67	143
	102	138	500	S	18	...	1/16	1/64	3.25	183
	69	127	400	———	———	not recorded	———	———	4.08	190
175	98	138	450	VS	18	20	1/64	Negl.	3.67	194
	103	149	500	VS	17	19	1/64	Negl.	3.08	198
Primary-air temperature, 550° F. Feed rate 3.0 gal./hr.										
	84	133	400	S	19	24	3/20	1/64	3.17	134
125	100	107	450	S	17	20	1/16	1/64	2.92	137
	94	121	500	S	18	21	1/16	1/64	3.33	142
	89	163	400	VS	19	21	1/64	1/64	2.75	182
175	104	120	450	S	17	20	1/32	1/64	2.50	184
	74	108	500	S	18	20	1/32	1/64	3.75	187

* M—Moderate C—Considerable MH—Moderately heavy
S—Small VS—Very small

Particle-Size Analysis

The particle size of the suspended dry powder was measured by a cascade-impactor sampling system. A cascade impactor was used for determining the particle-size distribution of the dried product. This was a standard model impactor manufactured by C. F. Casella Ltd. The inlet to this instrument was modified for connection to the sampling system, as suggested by Laskin (*24*), and a filter-paper stage was added to the exit of the impactor. A quick-opening sampling valve was used to limit the amount of sample admitted to the im-

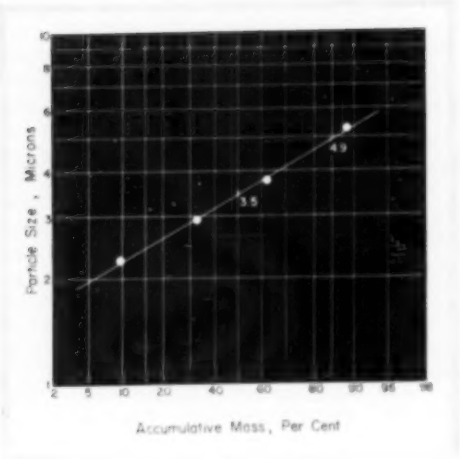
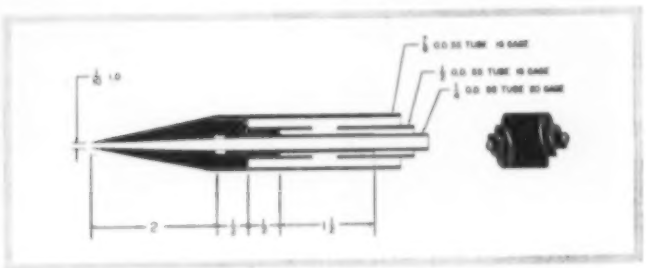


Fig. 5. Mass particle-size distribution of run 73.

Fig. 4. Liquid injector assembly.



pactor. This was necessary because of the relatively heavy loading of the dried product in the air stream. The quick-opening valve permits the air stream to flow around the impactor; the air is then adjusted to the flow rate that is to pass through the impactor (5); and, in this way, a short exposure of the impactor can be made with a minimum of disturbance. The probe for this system was made from 16-gauge ½-in. O.D. stainless-steel tubing. A sharp-edged entrance with a 0.20-in. opening was placed at the intake to the probe and flow rates were adjusted to obtain isokinetic sampling. Cascade-impactor samples were collected for the runs on sodium-sulfate solution after the cyclone samples were collected. Twenty sets of samples of approximately three-seconds exposure each were collected to obtain a satisfactory quantity of material for chemical analysis. Longer exposure periods gave erroneous results as excess material bounced off one stage and passed on to the next. Each set of samples consisted of material collected on four glass slides, one for each stage of the impactor, and that collected on a Whatman No. 41 filter paper at the exit of the impactor.

The glass slides were prepared by first washing them, rinsing with distilled water, and then allowing them to dry. These slides were then coated on one side with a mixture consisting of 50% xylene and 50% DuPont RL 233 nondrying alkyd resin. The xylene evaporated leaving a relatively thin film of resin on the slides. Care was taken not to allow the rate of air flow through the impactor jets to be greater than approximately one-half the sonic velocity (*9, 34*). Otherwise appreciable cooling and condensation will take place which will cause the particle-size determination to be in error. After the run, the samples were washed off the slides with distilled water and acetone, and the material collected on the filter paper was leached from the paper with distilled water. The samples for each stage were combined and the amount of sodium sulfate was determined by the tetrahydroxyquinone titration method (*8, 36*).

The four stages were first calibrated to determine the size range collected on each. This was done by sizing and counting the particles on the slides with a microscope equipped with an ocular micrometer. The particle-size distribution for each stage followed the log-normal distribution function and therefore the geometric-mass-mean diameter is the characteristic diameter for each stage of the impactor. If the same impactor is collecting the same material under conditions other than those at which it was calibrated, the characteristic diameter for each stage may be determined by the following relation (*33, 34*).

$$D_{Mg} = K\left(\frac{\mu_g}{C v_o}\right)^{1/2} \qquad (1)$$

The mass particle-size distribution of all the particles collected may be found by determining the mass of material collected on each stage of the impactor and plotting the mass per stage on the log scale against the characteristic diameter of each stage on log-probability graph paper (*24, 33, 34*). It is assumed implicitly that the mass characteristic diameter is equal to the volume characteristic diameter, that is, the densities of all of the particles are the same. The resulting graph was a straight line which confirms that the particle-size distribution is represented by the log-normal-distribution function (*13, 19, 25, 28*). Therefore, the mass particle-size distribution may be represented by two parameters, the geometric-mass-mean diameter D_{Mg} and the geometric-mean deviation σ_g. D_{Mg} may be found simply as the 50% size on the log-normal-distribution curve and σ_g is the ratio of the 84.13 to the 50% size. Other mean diameters may then be calculated by the following relations (*18, 19*).

$$\ln D_{Ng} = \ln D_{Mg} - 3 \ln^2 \sigma_g \qquad (2)$$

where D_{Ng} is the geometric-number-mean diameter.

$$\ln D_{Vg} = \ln D_{Mg} - 0.5 \ln^2 \sigma_g \qquad (3)$$

where D_{Vg} is the volume-to-surface-mean diameter.

Electron microscope photographs were taken of the dried sodium sulfate particles. These particles were collected on 200-mesh screens taped to clean microscope slides placed in the cascade impactor. These screens were coated with Formvar (polyvinyl formal) to form a membrane in the void spaces of the screens. The cascade impactor was exposed for a short time to the air sample, and the dried material was deposited on these membranes. Cadle (*9*) describes this method. The particles were found to be spherical and solid. Care was taken during the photography to avoid a high-intensity electron beam in the electron microscope. Otherwise the particles would vaporize and give false size measurements. When a high-intensity electron beam was used, it was observed that the dried sodium-sulfate particles were solid. They could be evaporated continuously down to a point before disappearing.

The mass particle-size distribution of the dried-particle diameters could be represented in all of the runs by the linear log-normal-probability function. This is in agreement with Hilvety (*20*), who found that the particle-size distribution followed this function. Geometric-mass-mean diameters D_{Mg} and geometric standard deviations σ_g measured by the impactor method for these runs are shown in Table 3. Figure 5 shows the mass-particle-size distribution of run 73. The distribution is a straight line on log-probability graph paper with a D_{Mg} of 3.5 μ and σ_g of 1.40. Volume-to-surface-mean diameters D_{Vg} were found for the dried material from Equation (3) and are listed in

Table 2.—Heat Added per Pound of Water Evaporated

Primary-air temperature,		350° F.	450° F.	550 F.
Secondary air temperature, ° F.	Primary-air rate, lb./hr.	B.t.u. added / lb. water evap.	B.t.u. added / lb. water evap.	B.t.u. added / lb. water evap.
	Feed rate 2.0 gal./hr.			
125	400	4,930	4,610	5,110
	450	4,560	5,210	5,430
	500	4,020	5,150	6,910
175	400	7,700	8,660	8,560
	450	8,520	8,560	8,730
	500	8,250	10,010	10,790
	Feed rate 3.0 gal./hr.			
125	400	2,410	3,760	3,330
	450	2,510	3,130	3,890
	500	3,530	3,850	4,000
175	400	6,080	5,900	5,570
	450	5,240	6,220	6,870
	500	5,950	5,060	6,490

Table 3.—Geometric Mass Mean Particle Diameter D_{Mg} and Geometric Standard Deviation σ_g

Primary-air temperature,		350° F.		450° F.		550 F.	
Secondary air temperature, ° F.	Primary-air rate, lb./hr.	D_{Mg} μ	σ_g	D_{Mg} μ	σ_g	D_{Mg} μ	σ_g
	Feed rate 2.0 gal./hr.						
125	400	3.7	1.50	3.5	1.54	3.5	1.51
	450	4.4	1.39	3.6	1.50	3.2	1.56
	500	4.3	1.44	3.3	1.52	3.5	1.51
175	400	4.2	1.36	3.5	1.49	3.6	1.47
	450	3.7	1.49	3.5	1.40	3.3	1.46
	500	3.3	1.51	3.3	1.46	3.4	1.50
	Feed rate 3.0 gal./hr.						
125	400	4.1	1.51	4.3	1.51	3.7	1.46
	450	3.8	1.61	4.1	1.51	3.5	1.54
	500	4.1	1.54	3.5	1.54	3.2	1.53
175	400	4.3	1.53	4.0	1.48	3.4	1.50
	450	3.8	1.50	4.0	1.53	3.7	1.46
	500	3.5	1.51	3.3	1.51	3.4	1.47

Table 4.—Volume-surface Mean Diameter D_{VS} and D_{VS}calc.

Primary-air temperature,		350° F.		450° F.		550 F.	
Secondary air temperature, ° F.	Primary-air rate, lb./hr.	D_{VS} μ	$D_{VS\ calc.}$ μ	D_{VS} μ	$D_{VS\ calc.}$ μ	D_{VS} μ	$D_{VS\ calc.}$ μ
	Feed rate 2.0 gal./hr.						
125	400	3.4	4.3	3.2	3.9	3.2	3.4
	450	4.2	4.0	3.4	3.5	2.9	3.2
	500	3.9	3.6	3.2 3.4, 3.0 3.1	3.3 3.3 3.3	3.2	3.1
175	400	4.0	4.3	3.2	3.9	3.4	3.6
	450	3.4	4.0	3.3	3.6	3.1	3.2
	500	3.1	3.6	3.1	3.3	3.1	3.1
	Feed rate 3.0 gal./hr.						
125	400	3.8	4.5	4.0	3.8	3.5	3.5
	450	3.4	4.0	3.8	3.6	3.2	3.2
	500	3.7	3.6	3.2	3.2	2.9	3.0
175	400	3.9	4.4	3.7	4.0	3.1	3.4
	450	3.5	4.0	3.7	3.6	3.5	3.2
	500	3.2 3.2	3.6	3.0	3.4	3.2	3.0

Table 4. These values were compared with the predicted values $D_{VS\ calc.}$. To obtain these, the predicted volume-to-surface-mean diameters of the wet atomized-liquid feed $\overline{D}_{VS}$ were first calculated by the Nukiyama and Tanasawa equation (*29, 30*) with the use of the data for sodium-sulfate solutions from the International Critical Tables (*21*). The volume-to-surface-mean diameters of the dried product $D_{VS\ calc.}$ were then calculated from $\overline{D}_{VS}$ by using a material balance. For this balance, a density of 1.03 g./cc. was used for the 5% aqueous sodium-sulfate solution, and a density of 2.70 g./cc., for the dried sodium-sulfate product. The material balance is represented by

$$(1.03)(.05)\frac{\pi}{6}\overline{D}_{VS}^{3} = (2.70)\frac{\pi}{6}D_{VS}^{3}{}_{calc.}$$

or

$$D_{VS\ calc.} = 0.267\overline{D}_{VS} \qquad (4)$$

Results of these calculations are also found in Table 4. The agreement between the two diameters, $D_{VS\ calc.}$ and D_{VS}, is good. The greatest difference between these is for a primary-air temperature of 350° F., but even this difference is not great.

The effects of the primary-air rate, the primary-air temperature, the secondary-air temperature, the feed rate, and their interactions on the geometric-mass-mean diameter were considered by the analysis-of-variance method (*14, 17*). Results of these analyses showed that the primary-air rate and the feed rate were of some importance, and the primary-air temperature was of major importance in the determination of the size of the dried particles. All the other variables and all the interactions were found to be of no significance. The primary-air rate was not varied over a sufficiently wide range to assess fully its effect. An increase in the primary-air temperature and the primary-air rate caused a decrease in the geometric-mass-mean diameter. This is to be expected since the Nukiyama and Tanasawa equation indicates that the dried-particle diameter decreases with an increase in primary-air velocity, which in turn increases with higher primary-air rates and temperatures. There was slight increase of particle size with an increase in the feed rate.

Calculation of Drying Time

The time required for the droplets to dry will be calculated for the conditions used in a typical run. The distance traveled by the droplets may then be

calculated from the calculated drying time. The calculated distance is then compared with the observations in the drying tube. These calculations are an aid to understanding the operation of the jet spray dryer and will be useful in scaling up the design for larger capacity.

The steps in the calculation consist of (a) predicting the velocity distribution in the drying tube, (b) calculating the initial volume-to-surface-mean diameter $\bar{D}_{VB}$ of the atomized droplets, and (c) integrating the heat transfer-heat balance differential equation for a particle traveling along a predetermined path through the drying tube. This gives a calculated value of the time of drying along the predetermined path. Since the axial component of the velocity is known as a function of the distance along the chosen path, the distance traveled by a particle during drying is determined by integration.

In this method of calculation the assumptions inherent are that: (1) the axial component of velocity may be adequately represented by the root-mean-square velocity neglecting the effect of the fluctuations on the heat balance, (2) Equations (7) and (8) below with the spreading coefficients used apply under the nonisothermal conditions in the drying tube, (3) the droplets evaporate essentially as pure water and the effect of the sodium sulfate on the wet-bulb temperature of the drops and the extent of a falling-rate period are second-order effects.

The spread of momentum, heat, and mass by turbulent diffusion in a free jet and in a jet in a duct has been considered by others (*1, 2, 3, 6, 7, 10, 16, 23, 35, 37*). Their methods will be used to calculate the velocity distribution in the drying tube. The velocity along the axis of an isothermal free jet (*1*) may be represented by the relation

$$\frac{u_{x,o}^2}{u_{o,o}^2} = \left(\frac{d}{2cx}\right)^2 \qquad (5)$$

The distribution of the axial component of the velocity along a radius for the same case is then given by

$$\frac{u_{x,r}^2}{u_{x,o}^2} = \exp.\left[-\frac{1}{c^2}\left(\frac{r}{x}\right)^2\right] \qquad (6)$$

For a jet in a secondary-air stream which moves with the velocity u_B, Equations (5) and (6) may be written

$$\frac{(u_{o,o}-u_B)^2}{(u_{o,o}-u_B)^2} = \left(\frac{d}{2cx}\right)^2 \qquad (7)$$

and

$$\frac{u_{x,r}-u_B)^2}{(u_{x,o}-u_B)^2} = \exp.\left[-\frac{1}{c^2}\left(\frac{r}{x}\right)^2\right] \qquad (8)$$

Measured values of c^2 as a function of $u_B/u_{x,o}$ are given by Ashmus (*6*) and by Kivnick (*22*) for isothermal flow of a jet in a secondary-air stream as represented by Equations (7) and (8). These values will be used to calculate the axial-velocity component distribution in the drying tube. The volume-to-surface-mean diameter $\bar{D}_{VB}$ is calculated from the Nukiyama and Tanasawa equation.

The conditions used in a typical run were as follows:

Primary-air nozzle diameter	0.65 in.
Feed rate	2.50 gal./hr.
Solids in feed	2.9%
Feed temperature	125° F.
Primary-air rate	114 cu.ft./min. (60° F. and 1 atm.)
Primary-air temperature	504° F.
Primary-air velocity through nozzle	1,385 ft./sec.
Secondary-air rate	1,000 cu.ft./min. (60° F. and 1 atm.)
Secondary-air temperature	123° F.
Drying-tube diameter	8 in.

The axial-velocity component vs. the radial distance from the centerline of the drying tube at four positions along the drying tube is shown in Figure 6. The calculated initial mean drop diameter $\bar{D}_{VB}$ is 11.5 μ. This will decrease to a mean diameter of the dry-solid spheres of 3.53 μ.

The time required for the sprayed droplets to dry was calculated from the rate of heat transfer to the surface of the droplets in a manner similar to that described by Marshall and Seltzer (*26, 32*). The heat transfer equation for spherical drops is

$$-\frac{\rho_l \lambda d\left(\frac{\pi D^3}{6}\right)}{d\theta} = h\pi D^2 (T_A - T_D) \qquad (9)$$

or

$$\frac{dD}{d\theta} = -\frac{2h}{\lambda \rho_l}(T_A - T_D) \qquad (10)$$

The value of h in Equation (10) may be estimated from the equation recommended by Ranz and Marshall (*32*) for heat transfer to spheres. After substituting values of ρ_g, μ_g, k and N_{Pr} for an average film temperature of 200° F., this equation becomes

$$h = \frac{11{,}000}{D} + 360\left(\frac{V}{D}\right)^{1/2} \qquad (11)$$

The time of drying and the distance traveled by the drops will be determined for two paths through the drying tube. The first path will be along the axis of the tube; the second will be along the boundary between the spreading jet and the secondary air. These should provide the two extremes that droplets may encounter in the course of drying. The first case will be calculated on the basis that the secondary air is not involved in the heat transfer-heat balance considerations; and the droplet temperature T_D is the wet-bulb temperature of the primary air until drying is complete. T_D is 125° F. An enthalpy balance for the droplets and the primary air may be written to obtain the air temperature T_A corresponding to any drop diameter D along the axis of the drying tube.

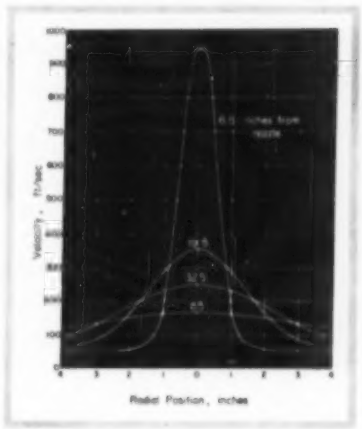


Fig. 6. Velocity vs. radial position.

At the nozzle with a nozzle velocity of 1,385 ft./sec. and an initial particle size of 11.5μ, $h = 960 + 3{,}960 = 4{,}920$ from Equation (11). At the end of the path the drops have attained the velocity of the air and the relative velocity is zero. For D equals 3.53μ, $h = 3{,}100 + 0 = 3{,}100$. An average value of $h = 4{,}010$ together with λ at 125° F. of 1,022, ρ_l of 62.4, are substituted in Equation (10) giving

$$\theta = \frac{-\lambda \rho_l}{2\, h_{avg}} \int_{11.5}^{3.53} \frac{dD}{(T_A - 125)} \qquad (12)$$

A drying time of 2.8×10^{-3} sec. was obtained by the graphical integration of this equation.

The length of travel required for the droplet to dry may be found by using the relation between the velocity $u_{x,o}$ along the axis and x in the following relation.

$$\theta = \int_0^x \frac{dx}{u_{x,o}} \qquad (13)$$

Integrating graphically, x is found to

be 21 in. downstream from the nozzle.

For the second case, the following conditions were used:

$u_{a,r}$ = secondary-air velocity, 53.5 ft./sec.
T_A = secondary-air dry-bulb temperature, 123° F.
T_D = secondary-air wet-bulb temperature, 70° F.
λ = the enthalpy of vaporation at 70° F., 1,054 B.t.u./lb.

With the employment of the same average h as in the first case but with consideration that droplets are exposed to the lower temperature of the secondary air, Equation (10) becomes

$$\theta = \frac{\lambda\rho_l(11.5-3.53)\times 3{,}600}{2\times(T_A-T_D)\times 30.5\times 10^4\times 3{,}100} = 18.8\times 10^{-3}\ \text{sec.} \quad (14)$$

These droplets travel 12 in. at a velocity of 53.5 ft./sec. before becoming dry. As an alternate calculation for the second case assume that the droplets immediately come to the velocity of the air stream and the relative velocity is always zero. Then the second term on the right of Equation (11) is zero, and

$$\theta = \frac{3{,}600\ \lambda\rho_l}{2(T_A-T_D)30.5\times 10^4\times 11{,}000}\int_{11.5}^{3.5} DdD = 40\times 10^{-3}\ \text{sec.} \quad (15)$$

and these drops travel 26 in. before becoming dry.

Calculations indicate that the drying is approximately at the same stage of completion across the duct at any particular axial distance downstream from the nozzle. Also, the drying is complete within 2 ft. from the nozzle. The periphery of the primary-air stream has spread to about an 8-in. diam. at this point as shown in Figure 6. Therefore, the use of an 8-in. drying tube is satisfactory according to these calculations.

This illustration is consistent with the available information for the jet spray dryer. In this typical run the drying was nearly complete at 19.5 in. downstream from the nozzle, and the wall deposition was small. The 8-in. drying chamber was satisfactory for this run.

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Notation

c = spreading coefficient for momentum, dimensionless
c_p = heat capacity of air at constant pressure, B.t.u./lb.
C = empirical correction factor for resistance of air to the movement of small particles

$$C = 1+\frac{2l}{D}[1.23+0.41\ \text{exp.}\ (-.44\ D/l)] \quad \text{for } 0.1<\left(\frac{2l}{D}\right)<134$$

d = diameter of primary-air nozzle, in.
D = particle diameter, μ or cm.; D', in ft.
D_{Mg} = geometric-mass-mean diameter, microns (μ)
D_{Ng} = geometric-number-mean diameter, (μ) (μ)
D_{VS} = volume-to-surface-mean diameter, (μ)
$\bar{D}_{VS}$ = volume-to-surface-mean diameter of liquid droplets predicted by Nukiyama and Tanasawa equation, microns (μ)
$D_{VS\ calc.}$ = volume-to-surface-mean diameter of dried solid spheres as calculated from solids content and $\bar{D}_{VS}$, microns (μ)
g_c = conversion constant
h = heat-transfer film coefficient, $\frac{\text{B.t.u.}}{(\text{hr.})(\text{sq.ft.})(^\circ\text{F.})}$
k_f = average thermal conductivity of gas film surrounding an evaporating drop, $\frac{(\text{B.t.u.})(\text{ft.})}{(\text{hr.})(\text{sq.ft.})(^\circ\text{F.})}$
K = a constant
l = mean free path of air molecule $= \frac{2\mu_g}{\rho\bar{v}}$, cm.
N_{Pr} = Prandtl number $= c_p\mu_g/k_f$
P = absolute pressure of air
r = radial distance from axis, in.
T_A = air temperature, ° F.
T_D = droplet temperature, ° F.
u_a = secondary-air velocity in axial direction, ft./sec.
$u_{a,o}$ = velocity on x axis or along the center line, ft./sec.; $u_{a,r}$ axial component at radius r and axial distance x
$u_{a,s}$ = primary-air velocity at nozzle, ft./sec.
v_a = air velocity through jet of impactor, ft./sec.
V = relative velocity between gas and liquid, ft./sec.
$\bar{v}$ = average molecular velocity of air molecules $= \sqrt{\frac{8Pg_c}{\pi\rho}}$, cm./sec.
x = axial distance from exit from primary-air nozzle, in.

Greek letters

θ = time
λ = latent heat of vaporization, B.t.u./lb.
μ_g = air viscosity, poises
μ_l = liquid viscosity, poises
ρ_g = density of gas surrounding droplets, lb./cu.ft.
ρ_l = liquid density, lb./cu.ft.
σ_g = geometric standard deviation

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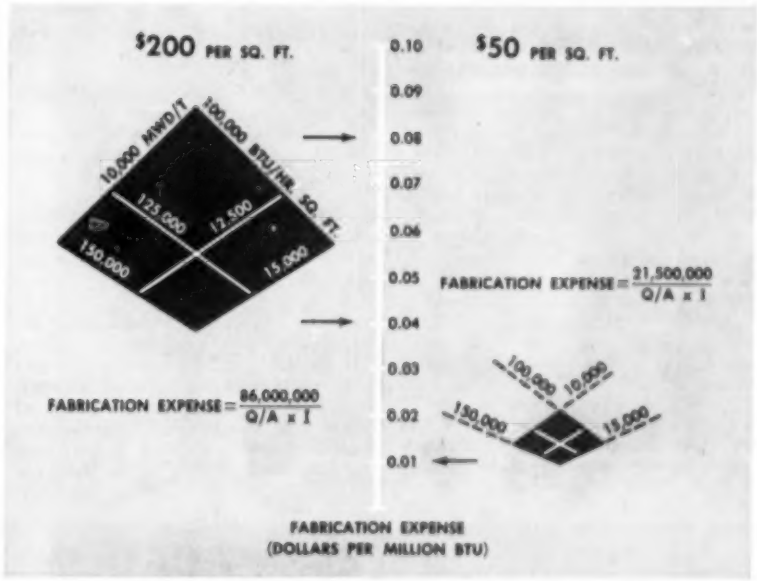

Fig. 5. Cost reduction by increase in both average heat transfer flux and irradiation level. Basis: reactor power, 250 mw.; reactor core diameter, 6.5 ft.

HEAT TRANSFER ECONOMICS

as related to design of nuclear fuel elements

A probe into the future of one phase of nuclear power plant operation suggests a tentative result: namely, fuel fabrication expenses may be in the neighborhood of five cents per million British thermal units. In the accompanying study, consideration is given to a 250-mw. pressurized-water reactor fueled with slightly enriched uranium oxide in rod form, clad with stainless steel.

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In the economic study of a nuclear power plant system it is of interest to examine nuclear Fuel Fabrication Expenses, not only as they exist today, but also as they may be a few years later. When plant sites and thermal-cycle equipment are selected for conventionally fueled power plants, the fuel costs and guaranteed fuel availability are usually surveyed for some twenty-five or more years into the future, and it is desirable to make similar analyses for nuclear power plants.

What fuel fabrication expenses may be after some operating experience with nuclear fuels has been gained is of particular interest, that is, at such time as shop procedures for fuel fabrication may have become routine, and when the limitations to radiation stability may have been fully established.

One cannot closely predict fuel fabrication expenses at some later date. However, by means of a parametric study of some variables involved, their effect on fabrication expenses can be considered. The approach here will be to look into some of the parameters which are important, and then to proceed in the following manner:

a) Identify those parameters which can vary only within a narrow range, and then fix reasonable values for these parameters.

b) Explore the effect of a few other variables over a wide range.

c) Draw certain tentative conclusions.

d) Reexamine the narrow-gauge variables to see if these conclusions are affected importantly.

For this study consideration will be given to the fuel fabrication expenses for a 250-mw. (P.W.R.) pressurized-water reactor fueled with slightly enriched uranium oxide in rod form, clad with stainless steel. For a reactor system such as this, some of the fuel parameters which can vary only within a narrow range are: the UO_2 density, the cladding thickness, the reactor solid-to-water ratio, the reactor height-to-diameter ratio, the uranium enrichment and value, and the power plant operating factor.

For the purposes of this parametric study the values foreseen are:

a) The density of the UO_2 will probably be 0.9, ± 10%, of the theoretical density of 10.9 g./cc.

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b) For strength purposes, to withstand vibration and internal gas pressures, the stainless steel tube wall will probably be 1/10 of the tube outside radius, ± 30% (or 1/20 of the tube O.D.).

c) The volumetric ratio between solid material and water in the reactor core will probably be 1.0, ± 25%.

d) The ratio of the reactor core height to its diameter will be approximately 1.0, ± 20%.

e) The uranium oxide starting enrichment, for inventory expense purposes, will probably be 2.5%, ± 30%.

f) The uranium oxide value, for inventory expense purposes, will be $300/kg., ± 40%.

g) The nuclear power plant will operate 7,000 hr./yr., ± 20%, for inventory expense purposes.

There are five other variables of importance. The effect of three of these, unit cost of heat transfer surface, average heat flux, and irradiation level will be considered over a wide range. The remaining two parameters, reactor core diameter and fuel rod outside radius, vary within a narrow range, but they are not really independent since they are directly or indirectly dependent upon the first three. The range of variation in these two parameters is:

a) reactor core diameter, which will probably be 6½ ft., ± 50%, and

b) fuel rod outside radius, which will probably be 0.25 in., ± 40% (or 0.50 in. in O.D., ± 40%).

The three independent variables which can vary over a wide range and which are studied here in greater detail are:

• *The unit cost of fabricating the tubular fuel element heat transfer surface.* For stainless steel heat exchangers currently in use in the chemical industry, heat transfer surface can be purchased from $20 to $50/sq. ft., such price depending upon the tubing diameter and the heat transfer duty of the heat exchanger. Stainless steel heat exchanger assemblies for use when filled with slightly enriched uranium, that is, nuclear fuel elements, are, as might be expected, much more expensive today. However, it can be expected that when shop procedures for this fuel element manufacture have become routine and when manufacturers can look upon actual manufacturing experience as a demonstration of their manufacturing costs, contingencies will be reduced. These unit costs may be considerably less in future years. In this study, we shall assume a range in unit shop fabrication costs from $200/sq. ft. down to $50/sq. ft. It is believed that firm quotations can be obtained for fuel element fabrication at less than $200/sq. ft. today. However, because of the smaller diameter tubing, the filling of the tubes with uranium oxide, the need for extraordinary testing, and the health-physics, criticality, and accountability precautions, there is reason to believe that nuclear fuel element fabrication costs may never quite become as inexpensive as the more common stainless steel heat exchangers. Thus a lower limit of $50/sq. ft. is selected.

• *There are limitations to the heat flux which can be removed from a tubular uranium oxide fuel element.* These limitations stem partially from the fairly low thermal conductivity of the uranium oxide and partially from the necessary margin which must be observed between the peak heat flux location in the reactor and the average heat flux. The transfer of heat to the pressurized water coolant is of lesser concern here. Here interest lies in average heat fluxes from 50,000 to 150,000 B.t.u./(hr.)(sq. ft.). Today the lack of operating experience leads to reactor designs near or below the mid-point of this range. However, it can be foreseen that improvements in the thermal conductivity and reduction in the peak-to-average heat flux ratio may lead to higher average heat fluxes, near the top of this range or beyond.

• *Uranium oxide is now believed to be generally stable under intense neutron irradiation, but the limits of this irradiation stability have not yet been determined.* Thus a study is made here of average irradiation levels from 5,000 to 15,000 mw. days/metric ton. The irradiation levels in peak burn-out areas will, of course, be higher than the average. Today, reactor designs are generally based upon irradiation levels that fall near the mid-point of this scale. In the future it is expected that radiation-stability experiments and actual-reactor operations will demonstrate that higher average irradiation levels may be achieved, insofar as radiation stability itself is concerned. Of course, sufficient reactivity must be introduced through initial enrichments, accompanied by sufficient control of the excess reactivity, to match the higher irradiation levels which are foreseen here.

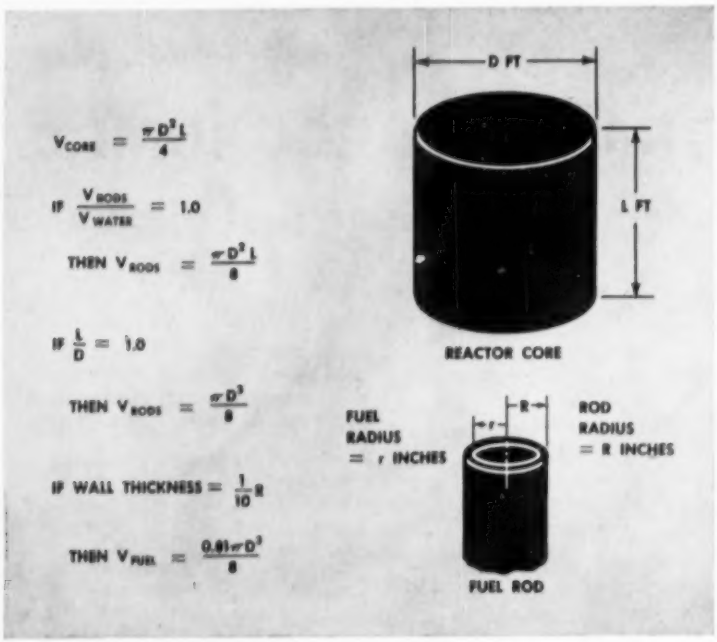

Fig. 1. Reactor fuel and core geometry.

$$\text{Fabrication expense (\$ per million B.t.u.)} = \frac{C \frac{\$}{\text{sq.ft.}} \times Q \frac{\text{mw.}}{\text{core}} \times 10^6 \frac{\text{g.}}{\text{ton}}}{Q/A \frac{\text{B.t.u.}}{\text{hr./sq.ft.}} \times I \frac{\text{mw. days}}{\text{ton}} \times 24 \frac{\text{hr.}}{\text{day}} \times \left[\left(\frac{r}{R}\right)^2 \left(\frac{V_{rods}}{V_{core}}\right) \frac{\pi D^2}{4}\right] \frac{\text{cu.ft.}}{\text{core}} \times \rho \frac{\text{g.}}{\text{cc.}} \times 28{,}320 \frac{\text{cc.}}{\text{cu.ft.}}} \quad (1)$$

$$\text{Fabrication expense} = \frac{0.43 \times 10^6 \, C}{Q/A \times I} \text{ \$/million B.t.u.} \quad (2)$$

Geometry of the Reactor Core

FUEL RODS, AND INTERRELATIONSHIPS BETWEEN RODS AND CORE

The total volume of the reactor core is, of course,

$$\pi D^2 L/4$$

where

D is the reactor core diameter

L is the active fuel height, both measured in feet.

If the volumetric ratio of solid materials to water is 1.0, for this example, then the volume of the fuel rods, including both the fuel and its cladding, can be expressed as $\pi D^2 L/8$. If the height-to-diameter ratio, the L/D ratio, is also 1.0, the volume of the fuel rods will be $\pi D^3/8$. Now if the cladding wall thickness is 1/10 the outside radius (or 1/20 the O.D.), the volume of uranium oxide fuel will be 0.81 times the total volume of the fuel rods, or 0.81 $\pi D^3/8$. (See Figure 1.)

It is now desired to compute the fabrication expense in terms of dollars per million British thermal units, for a wide range of variation in heat transfer surface unit cost (C), for various irradiation levels (I), and for various average heat fluxes (Q/A). These parameters, the geometric considerations just discussed, and the uranium oxide density (ρ) are interrelated in the expression for fabrication expense shown as Equation (1) on facing page.

With certain values for those parameters which can vary only over a narrow range, the effect of the variables C, Q/A, and I over a wider range can be considered in more detail. For example, if the reactor power level, Q, is 250 mw., if the uranium oxide fuel radius, r, is 0.9 times the fuel rod radius, R; if the volume of the fuel rods, V_{rods}, is 0.5 times the total reactor core volume, V_{core}; if the reactor core diameter, D, is 6.5 ft.; and if the uranium oxide density, ρ, is 0.9 times the theoretical density of 10.9 g./cc., the fabrication expense can be expressed as Equation (2) on facing page.

The next step covers the exploring separately of the range of fabrication expense for the range of average irradiation level with which this paper is concerned, that is, from 5,000 to 15,000 mw. days/metric ton. Figure 2, which is based upon an average heat flux of 100,000 B.t.u./(hr.)(sq.ft. of heat transfer surface), shows that if the heat transfer surface unit cost is $200/sq.ft., the fabrication expense will be as much as $.17/million B.t.u. or as little as $.06/million B.t.u. Of course, if the unit surface cost is less, the fuel fabrication expense may be less, in fact, much less.

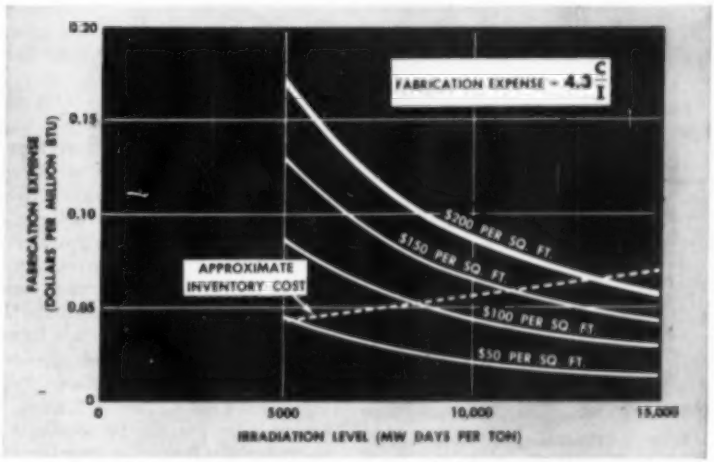

Fig. 2. Cost reduction by increase in irradiation level. Basis: reactor power, 250 mw.; reactor core diam., 6.5 ft.; average heat flux, 100,000 B.t.u./hr.-sq.ft.

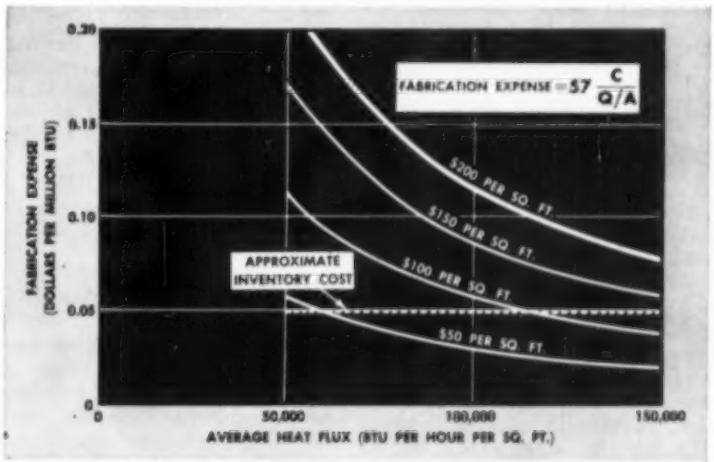

Fig. 3. Cost reduction by increase in average heat transfer flux. Basis: reactor power, 250 mw.; reactor core diam., 6.5 ft.; irradiation level, 7,500 mw.-days/ton.

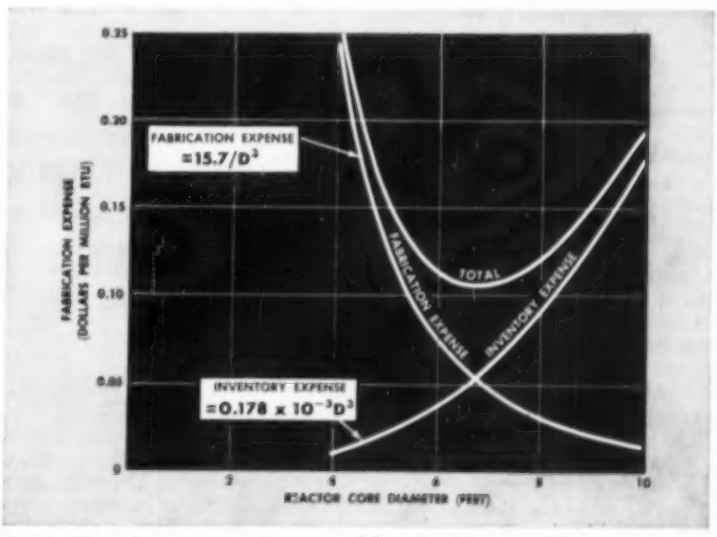

Fig. 4. Effect of reactor core diameter on fabrication expense and inventory expense. Basis: reactor power, 250 mw.; operating hr., 7,000 hr./yr.; value of UO_2, $300/kg.; irradiation level, 7,500 mw.-days/ton; unit fabrication cost, $100/sq.ft.; avg. heat flux, 100,000 B.t.u./hr.-sq.ft.

Table 1.

Irradiation level	Approximate reactor inventory expense
mw. days/ton	$/million B.t.u.
5,000	$.042
6,000	.044
7,000	.047
8,000	.049
9,000	.052
10,000	.055
11,000	.057
12,000	.060
13,000	.062
14,000	.065
15,000	.068

Table 2.—Fuel Rod Radius—Range of Variation

Heat flux avg. B.t.u./(hr.)(sq.ft.)	Core diameter 6.0 ft. Rad. in.	6.5 ft. Rad. in.	7.0 ft. Rad. in.
50,000	.120	.152	.190
75,000	.180	.228	.285
100,000	.240	.304	.380
125,000	.300	.380	.474
150,000	.358	.456	.569

The higher irradiation level will not come about without some additional inventory expense due to the higher initial enrichment which will be needed for the higher irradiation level. Although not a part of this fabrication expense study, one can compute that the reactor inventory expenses under these various conditions, based upon an enrichment of 2.5% for 7,500-mw.-days/ton, will be approximately as shown in Table 1.

One can see from Figure 2 that for this 250-mw. reactor core loading, 15,000 mw.-days/ton is a reasonable target for average irradiation level, both fabrication expense and reactor inventory expense being taken into account.

The effects of possible increases in the average heat flux are shown in Figure 3, these effects being based upon an average irradiation level of 7,500 mw.-days/ton. Under these circumstances, reactor inventory expense varies over a narrow range if the volume of cladding bears a constant relationship to the volume of uranium-oxide fuel, and thus reactor inventory expense is shown to be approximately $.05/million B.t.u., here, throughout the range of average heat transfer flux.

The selection of a particular average heat flux as a basis for detailed reactor core design dictates, to a certain extent, the fuel and radius and the reactor core diameter. For example, see Table 2 for the range of variation in each for the typical 250-mw. reactor.

There is also an economic balance between fabrication expense and inventory expense which affects the selection of reactor core diameter, and consequently fuel rod dimensions. Figure 4 shows, for example, that if one desires to achieve an average irradiation level of 7,500 mw.-days/ton and an average heat flux of 100,000 B.t.u./(hr.)(sq.ft.) for a 250-mw. reactor, the fabrication expense varies inversely as the cubic power of the reactor core diameter. Thus as reactor core diameter is increased, the heat transfer surface can be made to serve for a longer time period. However, this effect is counterbalanced by reactor inventory charges over this longer time period. In this example, the total of fabrication and inventory expense can be seen to be a minimum with a reactor core diameter of 6 to 7 ft.

The possible effect of gradual simultaneous increases in both the average heat transfer flux and the average irradiation level should also be studied. Figure 5 shows the range of fabrication expense for the lower and higher estimates of $50 and $200/sq.ft. of heat transfer surface, for 100,000, 125,000, and 150,000 B.t.u./(hr.)(sq.ft.), and for 10,000, 12,500, and 15,000 mw.-days/ton.

For $200/sq.ft., Figure 5 shows that fabrication expense in this range may be from $.04 to $.09/million B.t.u. For example, for $200/sq.ft. if the average irradiation level should be 10,000 mw.-days/ton and if the average heat flux should be 100,000 B.t.u./(hr.)(sq.ft.), the fuel fabrication expense would amount to $.08/million B.t.u. If these parameters are 15,000 and 150,000 respectively, the fabrication expense would be $.04/million B.t.u. If the unit cost of heat transfer surface should eventually be only $50/sq.ft., the fabrication expenses should be only $.01 to $.02/million B.t.u.

The effect of small variations in the parameters, fixed for this study, is outlined in the following paragraphs:

a) The possible error in fuel fabrication expense due to variation in the selected range of uranium oxide density (0.9, ± 10%) is approximately 10%.

b) Variations in the stainless steel wall thickness (0.1 times the outside radius, ± 30%) will affect the fuel fabrication expense at 15,000 mw.-day/ton by 7%.

c) Variations in the solid-to-water ratio (1.0 ± 25%) will affect the fuel fabrication expense by 13%.

d) Variation in the reactor core height-to-diameter ratio (1.0, ± 20%) will affect the fuel fabrication expense by 20%.

Cumulatively these four possible errors total ± 60%. The other independent parameters have been taken into account or do not affect fuel fabrication expense.

Thus, by over-all judgment of their error ranges, one may conclude tentatively that if technology continues to improve, fuel fabrication expenses may at some day in the future be, say, $.05/million B.t.u., and furthermore, that these expenses, based upon the assumptions made, will lie within the range of $.01 to $.09/million B.t.u.

Notation

C = cost of heat transfer surface
D = reactor core diameter
I = irradiation levels
L = active fuel height
Q = reactor power level
Q/A = average heat fluxes
r = fuel radius
R = fuel rod radius
V_{core} = core volume
V_{rods} = volume of fuel rods

Greek

ρ = uranium oxide density

Presented at the 1957 Nuclear Engineering and Science Congress, Philadelphia, Pennsylvania.

WHAT'S IN SYMPOSIUM SERIES VOLUME 52

*(Number 18, 1956—"Heat Transfer"—Louisville *)*

Correlation of Maximum-heat-flux Data for Boiling of Saturated Liquids

W. Rohsenow and P. Griffith

Since it was observed that bubbles "shoot" away perpendicularly from vertical surfaces, it appears that gravity should perhaps not have a significant effect on the peak heat-flux values. The correlation method proposed here is based on reasoning similar to that used in the development of the boiling heat transfer correlation employing the concept of a bubble Reynolds number.

Effect of Air Rate, Water Rate, Temperature, and Packing Density in a Cross-flow Cooling Tower

N. W. Snyder

Tests and analysis have been made on a small cross-flow water-cooling tower in order to study the process of enthalpy transfer in this system. Some results are briefly presented herein. The purpose is to present the energy-transfer performance for a small cross-flow tower as a function of air and water rates as well as water temperature and packing density. An attempt has been made to present an empirical formula which may be used by the engineer in his estimations on cooling systems.

* *$4.25 to non-members; $3.25 to members; 115 pages. Obtainable from offices of A.I.Ch.E., New York.*

MIXED CATALYSTS in production of PENTAERYTHRITOL

The accompanying article deals with the effect of using a catalyst composed of a mixture of two substances—sodium hydroxide and calcium hydroxide—in the production of pentaerythritol. Although this study cannot be considered a completely new concept, it is significant from the standpoint of reaction economics.

R. S. Valentine and M. S. Peters* | University of Illinois, Urbana, Illinois

Pentaerythritol is a polyhydric alcohol with a structure consisting of four methylol (CH_2OH) groups arranged around a single carbon atom. This material is particularly useful for many purposes because all the hydroxyl groups are equally reactive. Another important property of pentaerythritol is its high hydroxyl value. Theoretically, a smaller quantity of pentaerythritol is required to esterify a given amount of acid than any of the other common esterification agents.

The chemical nature of pentaerythritol suggests many diverse applications. It has been used as a constituent of paints, drying oils, floor coverings, waxes, cements, chewing gum, and explosives. More recently, pentaerythritol esters have been found to be excellent plasticizers for high-polymer plastics. The most rapidly expanding use of this substance at present, however, is in the production of resins. Resins produced with pentaerythritol can be controlled readily to give desired viscosity, hardness, flexibility, and drying rate. The quality of pentaerythritol resins is significantly higher than that of other resins with equivalent production costs.

Pentaerythritol is usually produced commercially by a base-catalyzed condensation of formaldehyde with acetaldehyde. The side products formed in the reaction have little commercial value relative to the value of the product pentaerythritol. Consequently, the economic production of pentaerythritol is primarily dependent upon the yields and quality of product that can be obtained.

Published information relative to the synthesis of pentaerythritol with a single base catalyst is restricted almost entirely to U. S. patents. Although there is some disagreement in the procedures followed and the yields claimed, the following conditions are generally agreed upon as satisfactory for purposes of commercial production (*3*):

- Concentration of formaldehyde = 4-5 moles/mole acetaldehyde
- Concentration of base catalyst = 1.5-1.6 equiv./mole acetaldehyde
- Water concentration = 12 moles/mole formaldehyde
- Reaction temperature = 30-80° C.
- Time of reaction = 1-6 hr.

Under these conditions, yields of 60-70% may be obtained employing pure calcium hydroxide as the catalyst and 70-80% with pure sodium hydroxide as the catalyst. All yields mentioned in this work are based upon the acetaldehyde charged.

Little information regarding the use of mixed catalysts for the production of pentaerythritol has been published. One investigator (*4*) recommended a catalyst composed of a mixture of alkyl ammonium hydroxides and alkalies such as sodium hydroxide, calcium hydroxide, and potassium hydroxide. With reaction times of 2-70 hr., this investigator realized yields of 80-90%.

In the present work, the only mixed catalysts employed were composed of sodium hydroxide and calcium hydroxide in varying proportions. All the experiments were conducted within the range of the conditions previously enumerated. The maximum yields attained were 90-95%.

Apparatus and Procedure

The variables examined in this work were reaction temperature, concentration of the mixed catalyst, reaction time, and formaldehyde concentration. In all experiments, the total amount of catalyst used was 3.64 equivalents, the amount of acetaldehyde charged was 100 g. and the water to formaldehyde ratio was 12 moles to 1.

In the experimental tests on the effect of catalyst concentration and reaction temperature, the initial ratio of formaldehyde to acetaldehyde was held constant at 5 moles to 1, and the reaction time was 90 min. at the desired reaction temperature. When investigating reaction time and formaldehyde concentration, the catalyst employed was 95 equiv. % of NaOH -5 equiv. % $Ca(OH)_2$, and the reaction temperature was 45° C.

A schematic diagram of the laboratory equipment for the preparation of pentaerythritol is shown in Figure 1. The procedure for a typical experimental run was as follows:

Distilled water, in the amount of 1,883 g., and 917 g. of technical grade (37.2 wt.%) formaldehyde were mixed in a 5-liter flask. The water and formaldehyde were cooled in a water bath and maintained below 25° C. while the mixed catalyst was added, the mixture being vigorously agitated at all times. The amount of base catalyst added varied from 145.5 g. for pure sodium hydroxide runs to 134.0 g. for pure calcium hydroxide runs. For example, the catalyst for a 90 equiv. % NaOH-10 equiv. % $Ca(OH)_2$ run consisted of $0.90 \times 145.5 = 131$ g. of sodium hyroxide plus $0.10 \times 134.0 = 13.4$ g. of calcium hydroxide. (Hereafter, equivalent per cent will be designated simply as per cent.)

To the mixture of catalyst, formaldehyde, and water, 100 g. of reagent-grade acetaldehyde were added over a 10-20 min. period. The acetaldehyde was added below the surface of the liquid. Care was taken to maintain the temperature below 25° C. and to continue the agitation during the acetaldehyde addition. Upon completion of the acetaldehyde addition, the reaction mass was heated rapidly to the desired operating temperature. After the reaction had progressed one and one-half hour at the desired temperature, it was stopped by neutralization with formic acid. Complete neutralization required from 40-80 g. of acid. The neutralized mixture was placed under a vacuum and concentrated to about one-third its original volume, or about 1 liter. The concentrate was checked to be certain of its neutrality and was then cooled to 5° C. and held at this temperature for 40 hr.

Crystals of pentaerythritol were recovered by centrifuging. They were then washed with four 50-cc. aliquots of cold distilled water, dried for 3 hr. at 105° C., and weighed. The mother liquor was again cooled to 5° C. to be certain all the insoluble pentaerythritol had been recovered.

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Yields: Calculation

The over-all yield for each experiment was calculated from a knowledge of the amount of acetaldehyde charged, the amount of dry pentaerythritol recovered, and the amount of product remaining dissolved in the mother liquor. A solubility of 6 g. of pentaerythritol/100 g. of mother liquor was used in calculating the over-all yields. This solubility was checked experimentally, and, as shown in Table 1, a solubility of 6 g./100 g. solution is conservative.

Table 1.—Solubility of Pentaerythritol in Mother Liquor at 5° C.

(Determined experimentally by reconcentration)

Original weight of saturated mother liquor, g.	Weight of reconcentrated mother liquor after pentaerythritol recovery, g.	Weight of pentaerythritol recovered, g.	Apparent solubility of pentaerythritol in mother liquor, g./100 g.
1,400	815	56	9.6
815	458	27	7.6
1,061	654	42	10.3
1,048	658	28	7.2

Table 2.—Commercial Specifications for Technical Grade Pentaerythritol. Results of Experimental Analyses for Delaware Product and a Typical Mixed-Catalyst Product

	% Monopentaerythritol	Hydroxyl value, %	Sulfate ash, %	M. P. range, ° C.	Color
Commercial specifications	84-88	46-48	<0.4	185-225	white
Delaware technical grade pentaerythritol	86.0	47.7	0.10	181-216	white
Typical mixed catalyst product ...	85.0	46.9	0.36	178-204	colored slightly

Table 3.—Experimental Results of Investigation on Effects of Reaction Time and Formaldehyde Concentration

(% NaOH in catalyst = 95)

Reaction temp., ° C.	Reaction time, min.	$HCHO/CH_3CHO$ mole ratio	Over-all yield, %	% Monopentaerythritol
45	300	5/1	87.7	80.6
45*	90	5/1	85.3	82.3
45†	53	5/1	70.8	85.8
45	90	4.5/1	80.4	73.4
45	90	4.0/1	67.0	64.2

* neutralized when coloration first appeared
† neutralized at start of heat release

Discussion of Experimental Results

EFFECT OF CATALYST CONCENTRATION ON YIELD

Yields of pentaerythritol are plotted in Figure 2 as a function of the per cent of sodium hydroxide in the mixed catalyst. As the amount of calcium hydroxide in the catalyst was increased, a striking change in the yield was noted. To illustrate this change, the yields at 45° C. may be considered. With 100% NaOH as the catalyst, the yield was 64.3%. However, with a catalyst containing 90% NaOH and 10% $Ca(OH)_2$, the yield increased to 94.5%. Further increase in the per cent calcium hydroxide resulted in a decreased yield.

In the ordinary methods of pentaerythritol synthesis, the yield is fixed by the amount of reagents used up in side reactions. The use of a mixed catalyst apparently causes an increase in the formation of pentaerythritol and a corresponding decrease in the formation of side products. Wyler (*4*) states that this effect of a mixed catalyst is not related to the speed of the reaction, but to the direction taken. According to Wyler, the mixed catalyst directs the course of the reaction to the production of CH_2OH groups rather than to the production of CHOH groups found in many of the side products.

EFFECT OF TEMPERATURE ON YIELD

The temperature effect on the yield is considerably different with a mixed catalyst than with a single catalyst. One can consider the yields at a catalyst concentration of 50% NaOH and 50% $Ca(OH)_2$. As shown in Figure 3, the yield increased with temperature up to 45° C., then decreased with further increase in temperature. With a pure sodium hydroxide catalyst, the yield was linear with temperature in the range of 30-70° C.

The probable reason for this phenomenon is that the rate of side-product formation increases considerably faster with temperature than the rate of pentaerythritol formation. The higher the amount of calcium hydroxide in the catalyst, the more pronounced this effect becomes. At 70° C., the amount of side products formed is so great at catalyst concentrations richer than 25% in calcium hydroxide that almost no pentaerythritol can be recovered, and the small amount that is recovered is of poor quality.

With reaction-time constant at one and one-half hours, the highest yields with mixed catalysts were found at 45° C. Therefore, 45° C. can be considered as the balance point above which the rate of side reactions becomes fast enough to have a detrimental effect on yield. Below 45° C., the effect of the mixed catalyst is not nearly so pronounced, so that maximum yields cannot be obtained in one and one-half hours.

CHARACTERISTIC BEHAVIOR OF THE MIXED CATALYST REACTION

Several characteristic phenomena must occur in order to obtain high yields with the mixed catalyst. These are a sudden release of heat, a color change, and a sudden decrease in formaldehyde concentration. The behavior of a typical run as a function of time is shown in Figure 4. It can be seen from Figure 2 that the occurrence of these phenomena is a function of reaction temperature and catalyst concentration. At lower temperatures,

ANALYSIS OF PRODUCTS

Pentaerythritol products obtained in this work were analyzed for monopentaerythritol content by the dibenzal method, hydroxyl value by acetylation, melting point range, sulfate ash, and, qualitatively, for color. The analytical methods followed were those given by the Hercules Powder Company, Inc. (*2*). Tests on a commercial product, Delaware technical grade pentaerythritol, gave results within commercial specifications in all cases. This substantiates the analytical results for the mixed catalyst products. Results of typical analyses are shown in Table 2.

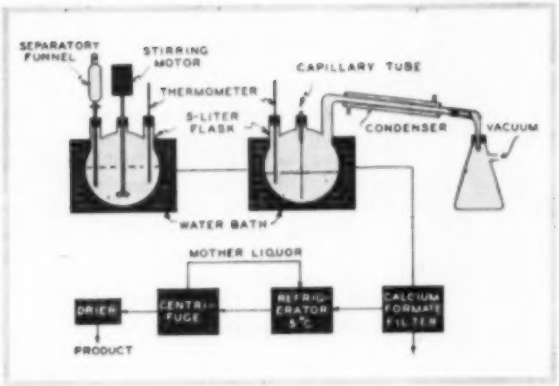


Fig. 1. Schematic diagram of laboratory equipment for the production of pentaerythritol.

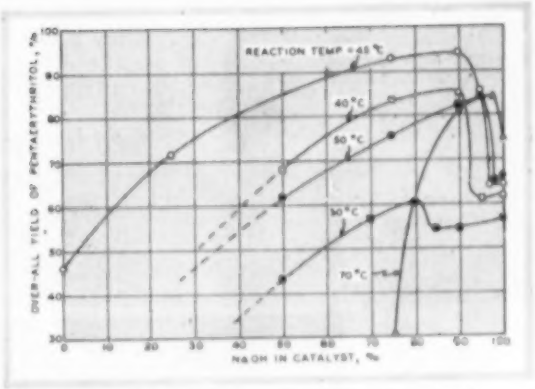


Fig. 2. Effect of catalyst concentration on over-all yield.

more calcium hydroxide is necessary in the catalyst to attain the high yields than at high temperatures. The heat release, color change, and sudden decrease in formaldehyde concentration are also characteristic of pure calcium hydroxide runs, but, unless they are controlled, they have a detrimental effect on the quality of the product.

The sudden heat release during the reaction is a function of the severity of the reaction, severity being proportional to temperature and calcium hydroxide concentration. As shown by Figure 4, the reaction may continue at the desired reaction temperature for a considerable period of time before the heat release occurs. At high severities, the heat release often takes place before the reaction can be brought to the desired reaction temperature. At low severities, it is quite possible that the sudden heat release would not occur, even after an extended period of time.

The heat release is accompanied by a corresponding sudden decrease in formaldehyde concentration, as shown in Figure 4. Heat is released until the formaldehyde concentration reaches zero. After this point, no higher yield can be obtained by allowing further reaction time.

When the release of heat subsides, the reaction mass begins to take on a coloration. At first, it is a pale yellow, which becomes increasingly darker with time until it is dark orange. The rate of coloration is also a function of severity of the reaction. At 70° C. and a catalyst concentration of 90% NaOH, the mixture takes only two minutes to go from pale yellow to dark orange. At 45° C. and 95% NaOH, more than 30 min. are required to produce the same amount of coloration.

A study of the kinetics of the pentaerythritol reaction by Cupit (*1*) shows that the pentaerythritol reaction proceeds rapidly and that, theoretically, a 90% yield of pentaerythritol could be obtained in a short reaction time. Cupit also reports that the formaldehyde left in the mother liquor can prevent the pentaerythritol from crystallizing out of solution. The decrease in formaldehyde concentration to zero which accompanies the heat release, and the course-directing effect of the mixed catalyst, are the factors which combine to give the high yields reported here. The apparent low yields in runs which did not exhibit the mixed catalyst effect may be, in part, due to the formaldehyde remaining in the mother liquor.

EFFECT OF REACTION TIME

The effect of reaction time on the yield and quality of pentaerythritol produced with a mixed catalyst was investigated, and the results are shown in Table 3. In one experimental run, the reaction was allowed to continue for several hours after the heat release occurred. The yield was increased only slightly over that obtained for a one and one-half hour run under the same conditions, and the product had a dark-tan color.

Runs which were neutralized immediately after the first slight coloration appeared were found to give high yields and a product that was almost pure white. Runs neutralized before the heat release occurred gave yields similar to those for 100% NaOH at the same temperature and a pure-white product.

EFFECT OF FORMALDEHYDE CONCENTRATION

Most runs were made with a formaldehyde-to-acetaldehyde ratio of 5 : 1. By decreasing this ratio to 4.5 : 1, then to the stoichiometric amount 4.0 : 1, it was found that lower yields of a poor-quality product were obtained. The effect of reaction time and formalde-

Fig. 3. Effect of reaction temperature on yield.

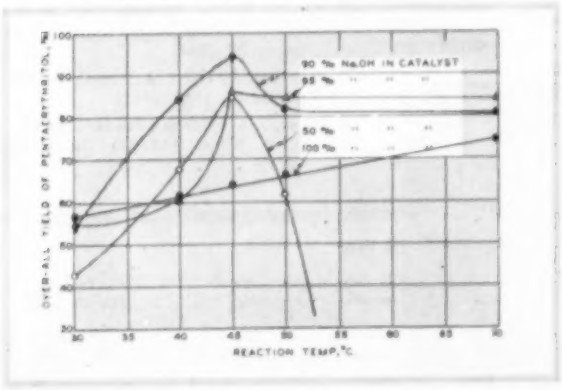
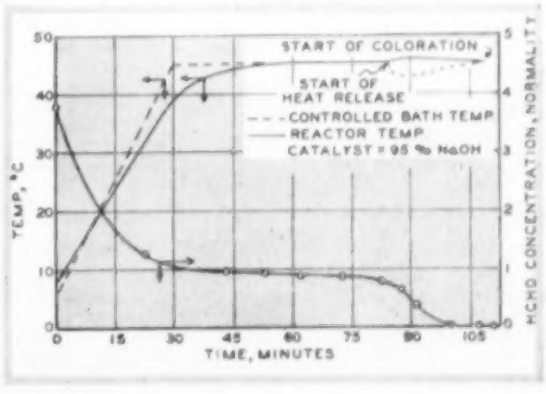


Fig. 4. Time behavior of a typical experimental run.



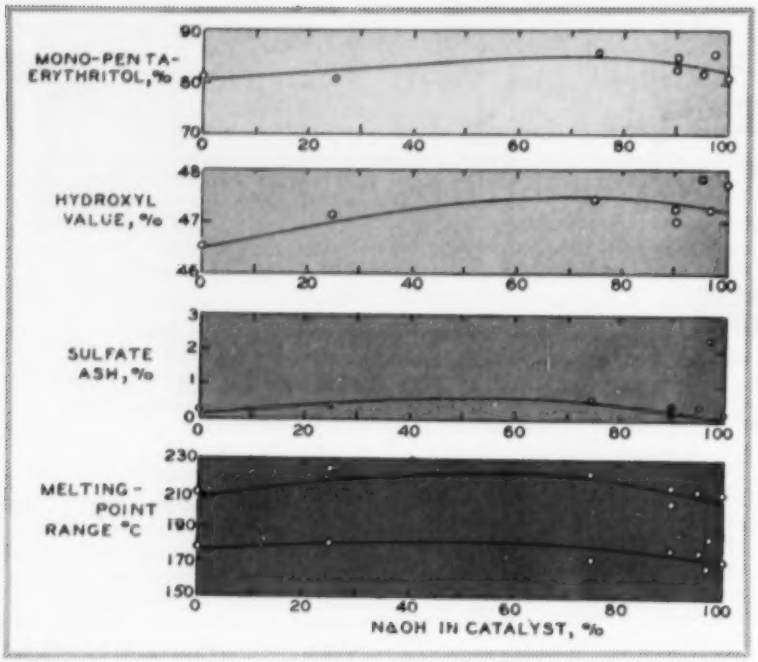


Fig. 6. Dependence of product quality on catalyst concentration. (Reaction temperature = 45° C.)

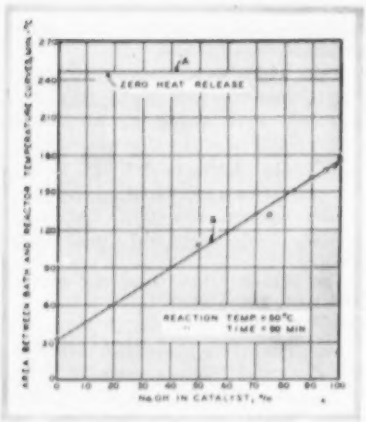


Fig. 5. Effect of catalyst concentration on heat release during pentaerythrose reaction.

hyde concentration is shown in Table 3. Other investigators have found that any increase in yield by use of a formaldehyde-to-acetaldehyde ratio higher than 5 to 1 does not warrant the extra expense for the formaldehyde.

HEAT EFFECT DURING THE PENTAERYTHROSE REACTION

The synthesis of pentaerythritol occurs by stepwise reactions in which the first stage is the production of pentaerythrose, as indicated by the following reaction:

$$3HCHO + CH_3CHO \xrightarrow{OH^-} C(CH_2OH)_3CHO$$

(pentaerythrose)

The second stage involves a Cannizzarro reaction with pentaerythrose, formaldehyde, and alkali to produce pentaerythritol. The reaction is

$$C(CH_2OH)_3CHO + HCHO + OH^- \longrightarrow C(CH_2OH)_4 + HCOO^-$$

(monopentaerythritol)

A qualitative estimate of the relative amount of heat released during the early stages of the reaction can be obtained by considering the area between the bath and reactor temperature curves during the initial heating period, as shown in Figure 4. The area between the curves provides a measure of how far the reactor temperature lagged the bath temperature. A series of such curves was plotted for various catalyst concentrations at a fixed reactor temperature of 50° C., and a definite correlation between the catalyst concentration and the area between the curves was noted. These results are presented in Figure 5.

The distance betwen line A and line B in Figure 5 is a measure of the amount of heat evolved in the early stages of the reaction. Results indicate qualitatively that the amount of heat evolved during the early stages of the reaction decreases linearly with the concentration of sodium hydroxide in the catalyst.

PRODUCT QUALITY

Figure 6 shows the quality of the pentaerythritol obtained from runs made at 45° C. Experimental runs made with mixed catalysts yielded as good or better a product than experimental runs made with 100% NaOH or 100% $Ca(OH)_2$ as the catalyst.

The products obtained in this investigation were similar to commercial products in hydroxyl value, but slightly lower in monopentaerythritol content and melting-point range. Most mixed-catalyst products were also slightly high in sulfate-ash content.

Recrystallization of products obtained with both single and mixed catalysts indicated that the ash content and the melting-point range could be improved considerably by further washing. Typical results are presented in Table 4. One refining step lowered the sulfate-ash content of a high-ash mixed-catalyst product from 1.20 to 0.33% and raised the melting-point range from 173-208 to 181-212° C. These values are similar to commercial specifications.

Pentaerythritol produced with a mixed catalyst had a slight coloration, the intensity of which was proportional to the severity of the reaction conditions. One recrystallization was found to remove all traces of color from a mildly colored product.

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3. Peters, M. S., and J. A. Quinn, *Ind. Eng. Chem.*, **47**, 1710 (1955).
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Table 4.—Experimental Data for Recrystallized Runs

Reaction temp., ° C.	Reaction time, min.	HCHO/CH_3CHO mole ratio	% NaOH in catalyst	Over-all yield, %	% Ash orig.	% Ash recryst.	M. P. orig., ° C.	M. P. recryst., ° C.
30	90	5/1	100	61.5	1.66	0.03	176-215	188-252
40	90	5/1	90	84.6	1.20	0.33	173-208	181-212

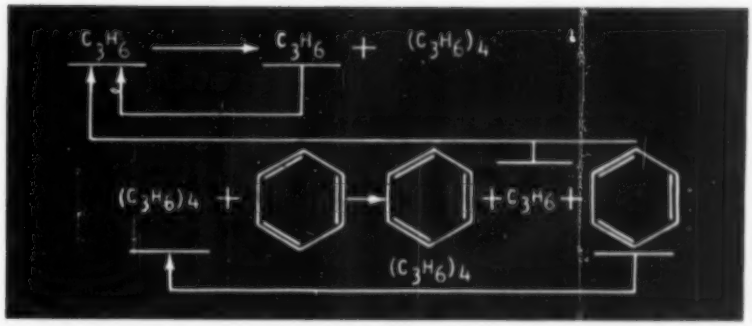

Fig. A.

MATERIAL BALANCE in complex and multistage recycle chemical processes

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Modern petroleum refineries tend to concentrate as many operations as possible in a single plant. This practice makes for considerable economies in intermediate storage and pumping facilities, for better use of waste heat and thereby for less fuel, cooling water, and other requirements. Such operations include straight distillation, lubricating oil production, cracking (both thermal and catalytic), polymerization, isomerization, alkylation, dehydrogenation, etc.

The manufacture of high-polymer products such as synthetic fibers, plastics, rubbers, and others takes place through a series of reaction stages. Each stage, especially in processes employing individual hydrocarbons as feed stock, is often associated with a low degree of conversion. This is explained by the desire to decrease by-product formation as far as possible. As a rule each reactor unit operates with recycling of the feed stock. In many cases, the inevitable formation of by-products leads to processes in which products of one reactor serve as raw material for others and vice-versa.

In polymerization (tetramerization) of propylene and the alkylation of benzene with the resulting dodecylene, it is observed that part of the propylene remains unchanged and that a certain amount is formed by depolymerization during the alkylation process. A schematic representation of this is shown in Figure A above.

This and the analogous schemes reproduced below are generalized flow diagrams of the reactions assuming unchanged feed stock; therefore, they have been constructed without the stoichiometric coefficients.

Similar to that for the production of dodecylbenzene is a flow diagram for obtaining butadiene from *n*-butane. The reaction is known to proceed in two stages, namely, dehydrogenation of the *n*-butane to butylene and of the latter to butadiene (see Figure B).

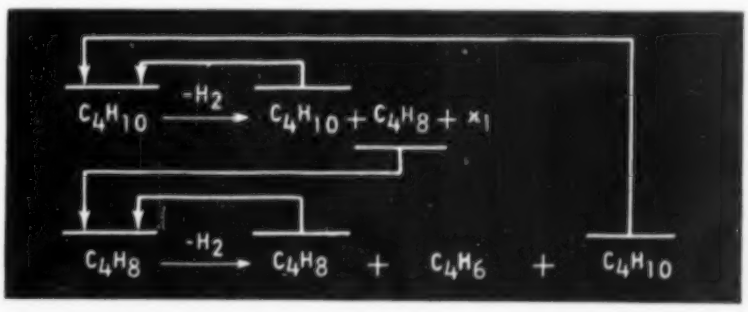
Calculation of the material balance of such systems presents a number of serious difficulties. The different units may include varying numbers of reaction stages. Moreover, each individual stage may operate with or without recycling, and with or without bleeding off of certain reaction products, as, for example, in hydrocarbon dehydrogenation or two-step hydrogenation of isoctene.

The objective is to determine the stream weights and the material balance both of individual reactors and of the integrated units, with partial or complete recycling. The material balance theory discussed here provides a means for the exact solution of this problem.

Derivation of General Expression for Reactor Charge

In its most general form, a combination of processes operating with recirculation is shown in Figure 1, which represents the integration of 1, 2, 3 . . . . *n* processes taking place in the separate units of a single plant. Each unit is equipped with the means

Fig. B.



for fresh stock supply and produces the raw material for further treatment in all other units of the system without exception. Hence each unit, in addition to a fresh charge, is being fed with stock recycled from all other units of the plant.

The symbols in Figure 1 are defined as follows:

$g_{1n}, g_{2n} \ldots g_{in} \ldots g_{mn}$ = total charges of the 1, 2, 3 . . . . . m^{th} reactor for the n^{th} *cycle*.

$g_{11}, g_{21}, g_{31} \ldots g_{m1}$ = charges of fresh stock for the 1, 2, 3 . . . m^{th} reactor.

$a_{1i}, a_{2i}, a_{3i} \ldots a_{ii} \ldots a_{mi}$ = component weight fractions in reactor effluent. The first subscript indicates the reactor from which the stream is emerging and the second the one to which it is going.

As a system of m reactors is being considered, obviously the second subscripts will change from 1 to m.

In accordance with the dynamics of the streams and taking into account their mutual combinations, the following charge values will obtain for each particular process:

$$\left.\begin{aligned}
g_{1n} &= g_{n} + g_{1(n-1)}a_{11} + g_{2(n-1)}a_{21} + \ldots + g_{i(n-1)}a_{i1} + \ldots + g_{m(n-1)}a_{m1} \\
g_{2n} &= g_{21} + g_{1(n-1)}a_{12} + g_{2(n-1)}a_{22} + \ldots + g_{i(n-1)}a_{i2} + \ldots + g_{m(n-1)}a_{m2} \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
g_{in} &= g_{i1} + g_{1(n-1)}a_{1i} + g_{2(n-1)}a_{2i} + \ldots + g_{i(n-1)}a_{ii} + \ldots + g_{m(n-1)}a_{mi} \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
g_{mn} &= g_{m1} + g_{1(n-1)}a_{1m} + g_{2(n-1)}a_{2m} + \ldots + g_{i(n-1)}a_{im} + \ldots + g_{m(n-1)}a_{mm}
\end{aligned}\right\} \quad (1)$$

Steady state operation of the entire system will theoretically set in at an infinite number of cycles. Hence, for the steady state at $n \to \infty$, system (1) assumes the following form:

$$\left.\begin{aligned}
(1-a_{11})g_{1n} - a_{21}g_{2n} - \ldots - a_{i1}g_{in} - \ldots a_{m1}g_{mn} &= g_{11} \\
-a_{12}g_{1n} + (1-a_{22})g_{2n} - \ldots - a_{i2}g_{in} - \ldots a_{m2}g_{mn} &= g_{21} \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
-a_{1i}g_{1n} - a_{2i}g_{2n} - \ldots + (1-a_{ii})g_{in} - \ldots - a_{mi}g_{mn} &= g_{i1} \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
-a_{1m}g_{1n} - a_{2m}g_{2n} - \ldots - a_{im}g_{in} - \ldots + (1-a_{mm})g_{mn} &= g_{m1}
\end{aligned}\right\} \quad (2)$$

Expression (2) is the system of basic simultaneous equations for determining the weights of the streams and the material balance of a highly complex series of processes. The Equations (2) are capable of solution, permitting calculation of the charge at the steady state for any reactor of the combined system.

The charge for the i^{th} reactor of an m reactor combination, Equation 3, results from the application of Cramer's rule:

$$g_{in} = \frac{\begin{vmatrix} (1-a_{11}) & -a_{21} & \ldots & g_{11} & \ldots & -a_{m1} \\ -a_{12} & (1-a_{22}) & \ldots & g_{21} & \ldots & -a_{m2} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ -a_{1i} & -a_{2i} & \ldots & g_{i1} & \ldots & -a_{mi} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ -a_{1m} & -a_{2m} & \ldots & g_{m1} & \ldots & (1-a_{mm}) \end{vmatrix}}{\begin{vmatrix} (1-a_{11}) & -a_{21} & \ldots & a_{i1} & \ldots & -a_{m1} \\ -a_{12} & (1-a_{22}) & \ldots & a_{i2} & \ldots & -a_{m2} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ -a_{1i} & -a_{2i} & \ldots & (1-a_{ii}) & \ldots & -a_{mi} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ -a_{1m} & -a_{2m} & \ldots & a_{im} & \ldots & (1-a_{mm}) \end{vmatrix}} \quad (3)$$

Expression (3) gives the general solution for the problem of the quantitative assessment of recycling processes. In particular, it enables determination of the recycling coefficient, of the weight of the individual streams and of the material balance for the hypothetical plant represented in Figure 1.

If the recycling system constitutes a single process, this will correspond to gas oil cracking, to single furnace light product reforming and also to synthetic processes involving individual components, such as simple dehydrogenation and molecular degradation. The general scheme for such a process is given in Figures 2a, 2b. In this case $i = 1$ and $m = 1$ and the total charge of the system according to Equation (3) will be

$$g_{1n} = \frac{\begin{vmatrix} g_n & 0 \\ 0 & 1 \end{vmatrix}}{\begin{vmatrix} (1-a_{11}) & 0 \\ 0 & 1 \end{vmatrix}}$$

whence:

$$g_{1n} = \frac{1}{1-a_{11}}\, g_{11} \text{ and } k_2 = \frac{1}{1-a_{11}} \quad (4)$$

where k_2 = recycling coefficient.

Formula (4) is identical with the recycling coefficient commonly found in the literature. In its general form the recycling coefficient is the ratio of the charge for the given reactor to the sum of the quantities of fresh feed stock for all reactors. From this it follows that each reactor has its own recycling coefficient. Multiplying each coefficient by the corresponding yield for a cycle (per pass) of unrecycled products, percentages are obtained the summation of which over all reactors of the combined system will be 100. It follows that on multiplication of the recycling coefficient proposed here for a combination of processes by the product yield for a single cycle (per pass) the reaction yields are obtained calculated on an over-all fresh feed basis.

If a number of substances are reacting in the system and it is required to determine the yields based on one component of the fresh feed stock, the recycling coefficient should be defined as the ratio of the given reactor charge

to the quantity of that component serving as basis for the calculation.

In dealing with the system of equations (1) at $n \to \infty$ and with Equation (3) one should bear in mind that when each reactor is supplied with a number of fresh stocks, then

$$g_{i1} = g'_{1m_1} + g'_{2m_1} + g'_{3m_1} + \ldots + g'_{km_1}$$

$$a_{ii} = a_1' + a_2' + a_3 + \ldots + a_k'$$

where the primes refer to the individual components of the stock mixture.

The system of equations (1) at $n \to \infty$ and Equation (3) are fundamental generalizations covering all aspects of operations involving recycling and combinations. These expressions may therefore be applied in an infinite number of circumstances, any chemical process operating with recycling being treated as a particular case.

Equations (1) at $n \to \infty$ or the determinant (3) permit an exact balance to be made of the operation of any combination of complex installations and a precise determination of the weight stream in the design of the individual units of the system.

Certain Aspects of Balance Calculations

In the calculation of the possible variants of processes with recycling, it appears to be feasible to separate such problems into two groups: those wherein only a part or all of the g_{im} are unknown and those where all the g_{im} and a_{ii} or some of them are unknown. Both groups of problems may be solved by means of Equations (3); but in the second case additional equations are required, expressing the values of the unknown a_{ii} through the initial conditions or the corresponding g_{im}. It is therefore convenient to solve the second group of problems by Equations (1) and to solve the respective auxiliary equations for the unknown a_{ii}.

Without the aid of this proposed method it would be a cumbersome task to calculate the material balance of combined processes with recycling from the results of laboratory experiments or to design the appropriate apparatus.

The principal advantage of the method is that for the calculation of the weights of the separate streams and the over-all material balance, data on the once-through yields for each reactor in the steady state are sufficient.

PRACTICAL APPLICATION OF THE THEORY OF RECYCLING

The two aforementioned cases will be illustrated by a number of concrete examples, those operations that have no effect on the number of streams determining the material balance of the process being omitted.

CASES OF THE FIRST GROUP

In the first group are included processes with known outputs per pass from every reactor, that is, with known steady state values for a_{ii}, and with completely or partially unknown feeds g_{im}.

For example: A heavy gas oil fraction from an arbitrary crude is being subjected to a double-furnace cracking. After cracking in the first furnace, a wide range gas oil cut is produced which is separated into heavy and light fractions. The heavy fraction is returned to the furnace as recycling stock and the light fraction is passed on to the deep cracking furnace which also yields heavy and light recycling stock that is cracked after being mixed with the corresponding products from each of the units. The technological and flow diagrams for this process are presented in Figures 3a and 3b.

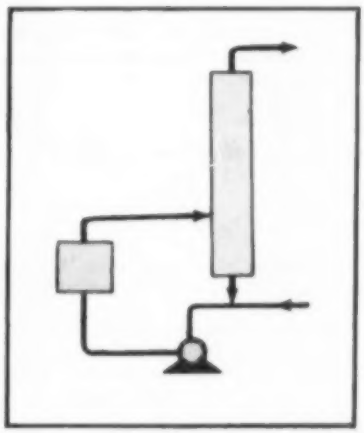


Fig. 2a. Simple flow diagram illustrating the principle for a one-reactor unit with recycling.

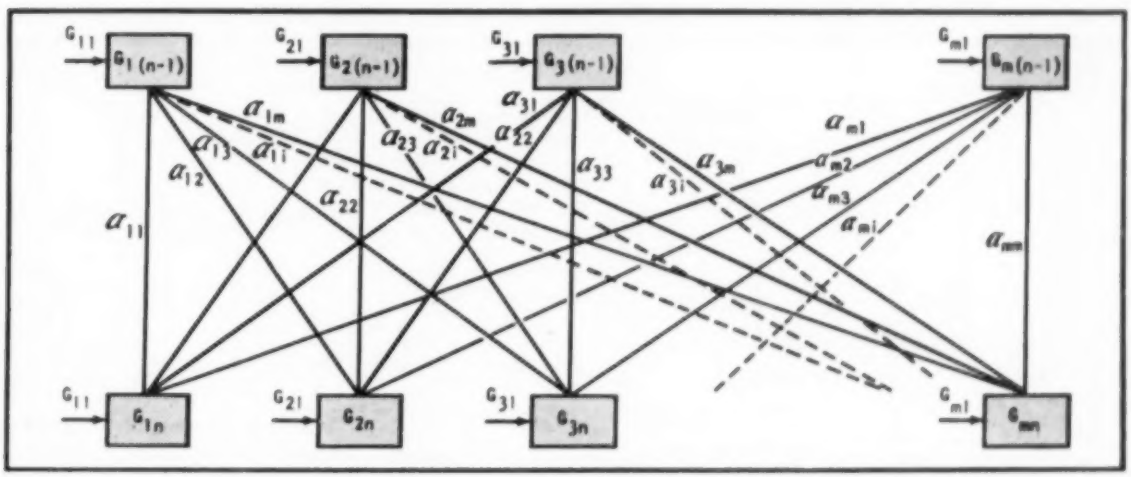


Fig. 1. Above, flow diagram for a complex plant.

Fig. 2b. Flow scheme for a one-reactor system.

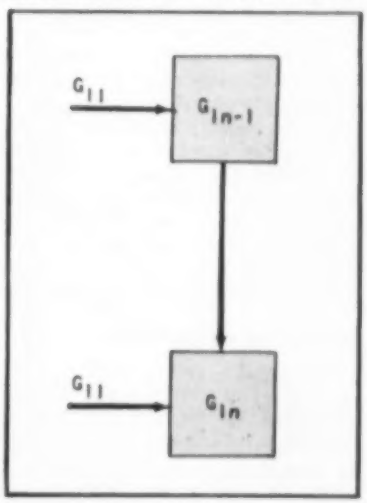


Table A.—Given: The following percentages by weight of the components.

Fresh feed stock	*n*-Butane isomerization products	Dehydrogenation products
$C_3H_8 - \delta_{Hn} = 5.2$	up to $C_3 - a_i = 2$	up to $C_3 - \gamma_i = 6$
$H\text{-}C_4H_{10} - \delta_H = 6.4$	$H\text{-}C_4H_{10} - a_i = 50$	$i\text{-}C_4H_8 - \gamma_{Hn} = 25$
$i\text{-}C_4H_{10} - \delta_i = 4.0$	$i\text{-}C_4H_{10} - a_H = 48$	$i\text{-}C_4H_{10} - \gamma_i = 69$
up to $C_5 - \delta_i = 61.3$		
C_5 and heavier $- \delta_n = 23.1$		

In Figure 3b

g_{1n} and g_{2n} = heavy and light furnace charges respectively.

a_{11}, a_{21} = recycling yields of high-boiling products from the heavy and light cracking furnaces.

a_{12}, a_{22} = recycling yields of low boiling products from the heavy and light cracking furnaces.

In accordance with the flow diagram (Figure 4b), formula (3) gives, for the first furnace charge

$$g_{1n} = \frac{\begin{vmatrix} g_n & -a_{21} \\ 0 & -a_{22} \end{vmatrix}}{\begin{vmatrix} (i - a_{11}) & -a_{21} \\ -a_{12} & (1 - a_{22}) \end{vmatrix}}$$

whence

$$g_{1n} = \frac{1 - a_{22}}{(1 - a_{11})(1 - a_{22})} g_n$$

For the light cracking furnace the formula gives

$$g_{2n} = \frac{\begin{vmatrix} (1 - a_{11}) & gn \\ -a_{12} & 0 \end{vmatrix}}{\begin{vmatrix} (1 - a_{11}) & -a_{21} \\ -a_{12} & (1 - a_{22}) \end{vmatrix}}$$

whence

$$g_{2n} = \frac{a_{12}}{(1 - a_{11})(1 - a_{22}) - a_{12}a_{21}} g_{11}$$

It is assumed in this and subsequent examples that cooling of the emerging streams is accomplished so as not to affect the quantity of input flow. But if the cooling agent or some other factor changes the stream characteristics and thus influences the material balance, this change must be taken into account in contracting the flow diagram, after which the calculations again may be made with formula (3).

CASES OF THE SECOND GROUP

The second group includes those cases in which part or all of the unit charges g_{in} and the recycling yields a_{ij} are unknown. This is illustrated by the processing of a gaseous mixture in which the sum of the isobutane and *n*-butane contents considerably exceeds that of the butylenes.

The process includes polymerization of the unsaturated components of the feed stock up to C_3, alkylation of the isobutane with the butylenes, isomerization of the normal butane and the withdrawal of gases formed during isomerization. The plant layout and flow diagram are reproduced in Figures 4a and 4b.

The symbols in Figure 4b have the following meanings:

g_{ii} = quantity of fresh gaseous feed stock.

$g_{1n}, g_{2n}, g_{3n}, g_{4n}, g_{5n}$ = the charges for the processes of distillation, polymerization, alkylation, isomerization and dehydrogenation, respectively.

a_{ij} = quantities of the various recycling stocks

In accordance with the diagram (4b) the following initial conditions obtain:

$i = 5$ and $n = 5$

$$\left.\begin{aligned} &g_{21} = g_{31} = g_{41} = g_{51} = 0 \\ &a_{11} = a_{14} = a_{15} = 0 \\ &a_{21} = a_{22} = a_{23} = a_{24} = a_{25} = 0 \\ &a_{31} = a_{32} = 0 \\ &a_{41} = a_{42} = 0 \\ &a_{52} = a_{53} = a_{54}\ a_{55} = 0 \end{aligned}\right\}$$

In contrast with the cases of the first group, this illustration is characterized by the fact that not all the components in each stage are subject to chemical change. Thus, for example, the first process in the flow scheme (Figure 4b) is designed for the purpose of simple fractionation, and, therefore, the recycle stock from the dehydrogenation cycle changes the component ratio in this unit, whereas the presence in the latter of butane in turn affects the component ratios of the alkylation, isomerization, and dehydrogenation processes of the plant.

The presence of excess isobutane, formed from the isomerization of the normal compound, owing to the lack in the feed stock of butylenes for its alkylation, has to be distributed between the alkylating and dehydrogenating units so that there is no excess either of isobutane or of the butylenes, in particular of isobutylene produced in the dehydrogenation of isobutane. Obviously, solution of this problem must be based on the yields for the isomerization of butane and the dehydrogenation of isobutane. In Table A the pertinent initial data for the calculation are given.

It is assumed that in the alkylation process equimolar quantities of the alkanes and alkenes take part; that is, the consumption of reactants in forming the alkylate is determined by the ratio 58/56 (mol weight ratio).

In conformity with the dynamics of the flows (Figure 4b) and the given initial data:

$$a_{12} = \frac{g_{11}\delta_i + g_{5n}\gamma_i}{g_{1n}} \tag{11}$$

$$a_{13} = \frac{g_{11}(\delta_{Hn} + \delta_H + \delta_i) + g_{5n}(\gamma_i + \gamma_{Hn})}{g_{1n}} \tag{12}$$

$$a_{34} = \frac{g_{11}\delta_H}{g_{3n}} \tag{13}$$

$$a_{35} = \frac{g_n\delta_i + g_{511}\gamma_i + g_{411}a_{43} - (g_{11}\delta_{Hn} + g_{5n}\gamma_{Hn})\mu}{g_{3n}} = \frac{g_{5n}\gamma_i}{g_{3n}} \tag{14}$$

If a fivefold excess of isobutane is assumed in the alkylation process, then

$$a_{33} = \frac{5\mu(g_{11}\delta_{Hn} + g_{5n}\gamma_{Hn})}{g_{3n}} \tag{15}$$

$$a_{43} = \frac{(g_{11}\delta_{Hn} + g_{5n}\gamma_{Hn})\mu - g_{11}\delta_i}{g_{4n}} \tag{16}$$

$$a_{44} = a_H. \tag{17}$$

$$a_{45} = a_i - a_{43}. \tag{18}$$

$$a_{51} = 1. \tag{19}$$

The simplest way of solving this problem is to determine the values for $g_{1n}, g_{2n} \ldots g_{5n}$ from the system of Equations (1) at $n \to \infty$ of from (2).

For the given case, from (1) at $n \to \infty$ one has

$$\left.\begin{aligned} g_{in} &= g_{11} + g_{5n}a_{51} \\ g_{2n} &= g_{1n}a_{12} \\ g_{3n} &= g_{1n}a_{13} + g_{4n}a_{43} + g_{3n}a_{33} \\ g_{4n} &= g_{3n}a_{34} + g_{4n}a_{44} \\ g_{5n} &= g_{4n}a_{45} + g_{3n}a_{35}. \end{aligned}\right\}$$

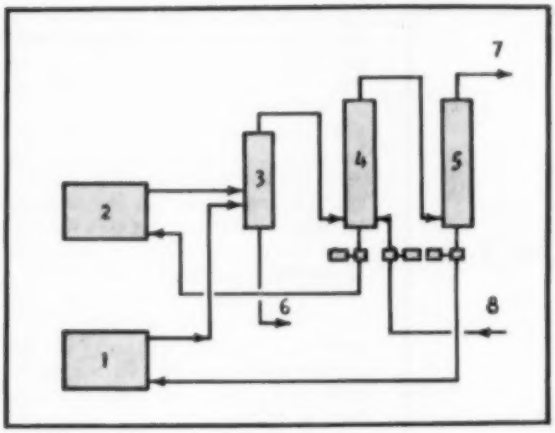
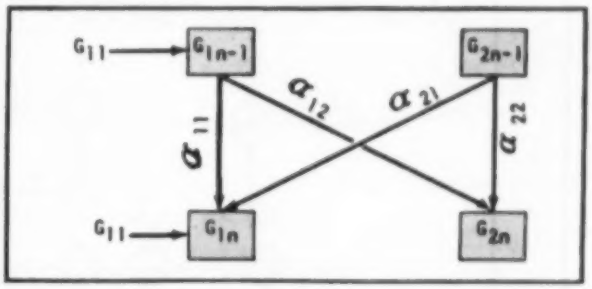


Fig. 3a. Scheme for a two-furnace cracking unit.

Fig. 3b. Flow diagram for a two-furnace cracking unit.



Solving (1) together with Equations (11) through (19) and assuming that $g_{11} = 1{,}000$ tons/day result in the following values of the desired parameters:

$g_{1n} = 1083.64$	$a_{12} = 0.5703$	$a_{43} = 0.2774$
$g_{2n} = 618.00$	$a_{13} = 0.2165$	$a_{45} = 0.2026$
$g_{3n} = 647.70$	$a_{34} = 0.0988$	$a_{44} = 0.5$
$g_{4n} = 128.00$	$a_{35} = 0.0891$	$a_{51} = 1.0$
$g_{5n} = 83.64$	$a_{33} = 0.5829$	

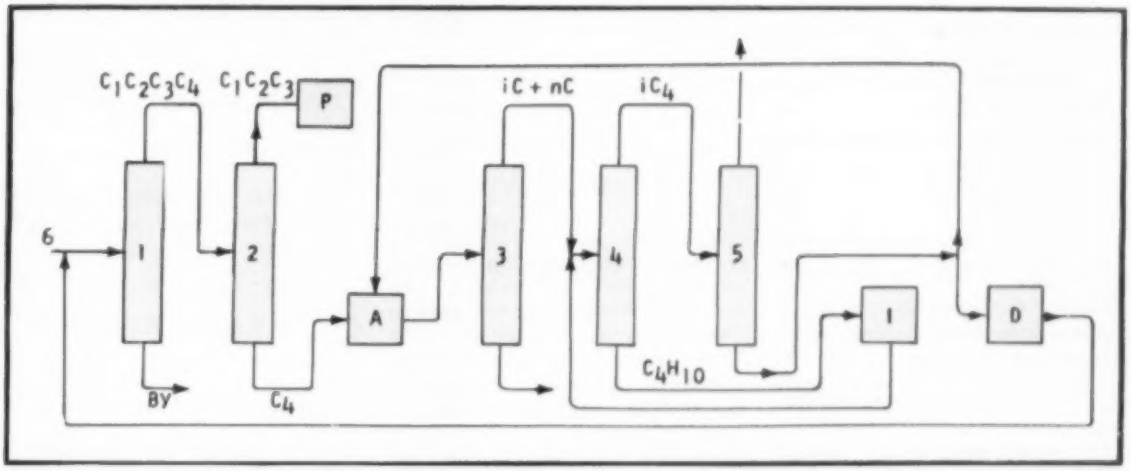


Fig. 4a. Scheme of a complex plant for the processing of cracking gas. *A*, *I*, *D*, and *P* are the corresponding reactors for alkylation, isomerization, dehydrogenation, and polymerization. 1 through 5 are rectification columns, 6 is fresh feed stock.

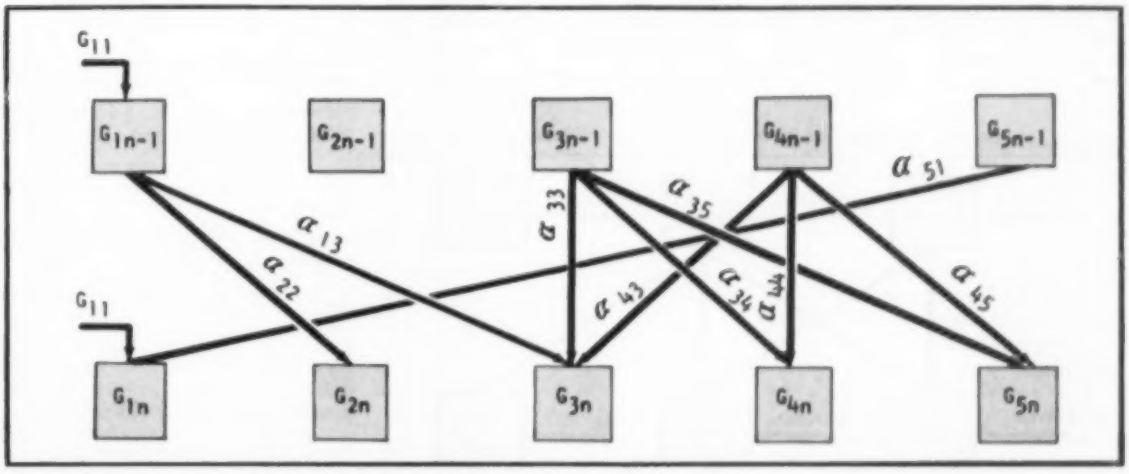


Fig. 4b. Flow scheme of a complex plant for the processing of cracking gas.

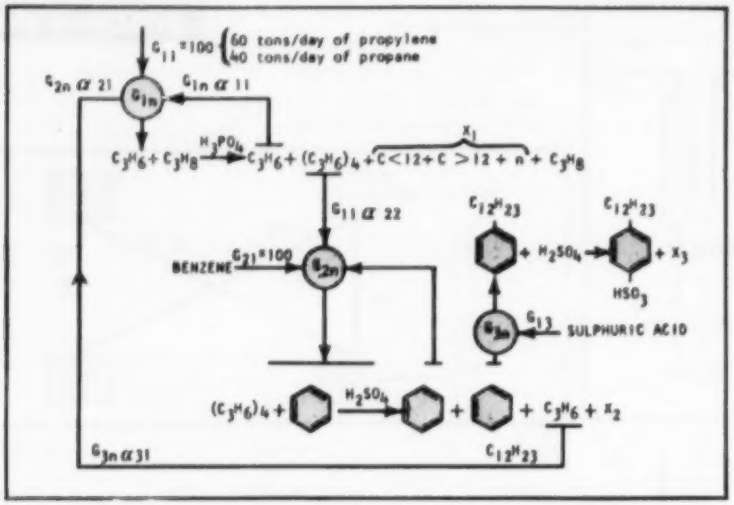


Fig. 5a. Scheme of the complex process of alkylaryl sulfonate production.

From the calculated data it follows that the over-all material balance of the plant is

Quantity of alkylate	$g_{3n}(1 - a_{32} - a_{34} - a_{35}) = 148.45$
Fraction up to C_3 consumed in the polymerization process	$g_{2n} = 618.00$*
Higher hydrocarbons	$g_{11}\delta_o = 231.00$
Fraction up to C_3 emerging after the polymerization	$g_{4n}a_1 = 2.56$
	total: 1,000.01 tons/day.

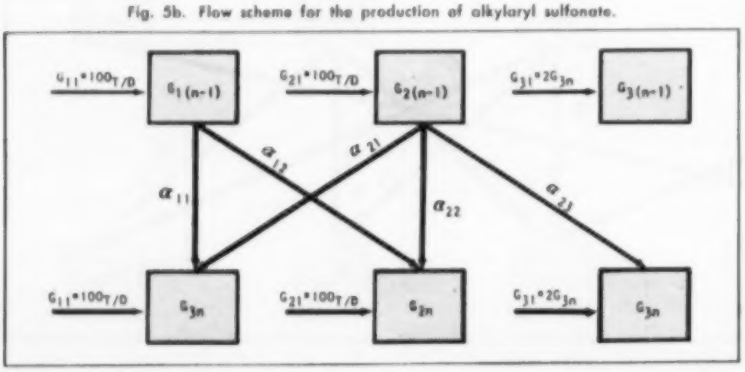
The disagreement is insignificant, being 0.001%.

Hence, the proposed method is highly accurate, leading to a remarkable agreement in the balances and to precise determination of the stream quantities for the individual units of highly complicated processes.

For further clarity another example will be considered, namely synthesis of the detergent, dodecylbenzene sulfonate from petroleum. The fresh feed stock is the propane-propylene fraction, the latter compound being polymerized on a phosphoric acid catalyst. The dodecylene fraction obtained goes to alkylate benzene. After alkylation the dodecylbenzene produced is further sulfonated. The monomer (propylene) formed in the alkylating process as a result of depolymerization is returned for polymerization together with the propylene that had passed through unchanged during the polymerization process. The process is schematically illustrated in Figure 5a, and a flow diagram for calculation of the material balance is presented in Figure 5b.

* In this example there is determined the total stock fed to the polymerization reactor. Knowing from experiment the data on the yields of individual compounds in this unit, g_{2n} may be separated into individual components.

Fig. 5b. Flow scheme for the production of alkylaryl sulfonate.



Let the daily capacity on the basis of the propane-propylene fraction (60% propylene and 40% propane) g_{11} be 100 tons and, on the basis of benzene, $g_{12} = 100$ tons.

It is considered that propane does not participate in the reaction, has no effect on the polymerization process, and does not appear in the recycled products; therefore, although the reactor charge will increase as the result of recycling, the absolute propane content (40 tons/day) will remain constant. Owing to this, the relative composition (weight fraction) of the polymerization products leaving the reactor will change and must be calculated as follows:

The weight fraction of propane will be $40/g_{1n}$ and of the rest of the components:

$$a_i = \frac{(g_{1n} - 40)P_i}{g_{1n}(1 - 0.4)} \qquad (20)$$

where the P_i are the yields of the individual products (weight fractions) during polymerization of the fresh stock, without recycling.

The initial data on the product composition is summarized in Table 1.

Using Equations (1) or the determinant (3) one writes the balance for the several stages and the process as a whole.

According to the chart (Figure 5b), for the steady state that sets in at $n = \infty$ and $g_{31} = 2g_{2n}a_{23}$.

$$g_{1n} = g_{11} + g_{1n}a_{11} + g_{2n}a_{21} \qquad (21)$$

$$g_{2n} = g_{12} + g_{1n}a_{12} + g_{2n}a_{22} \qquad (22)$$

$$g_{3n} = g_{2n}a_{23} + 2g_{2n}a_{23} = 3g_{2n}a_{23}. \qquad (23)$$

Substituting (20) in (21) and using the value of $a_{21} = 0.05$ from Table 1, yields

$$g_{1n} = g_{11} + \frac{(g_{1n} - 40)0.1}{0.6} + 0.05\, g_{2n}$$

whence

$$g_{1n} = 1.2\, g_{11} + 0.06\, g_{2n} - 8 \qquad (24)$$

Substituting (21) in (22) and the value for $a_{22} = 0.25$ gives

$$g_{2n} = g_{12} + \frac{(g_{1n} - 40)0.4}{0.6} + 0.25\, g_{2n}$$

whence the charge of the benzene-alkylating reactor will be

$$g_{2n} = 1.3333\, g_{12} + 0.8889\, g_{1n} - 35.5556 \qquad (25)$$

Equations (24) and (25) contain two unknowns g_{1n} and g_{2n} which are determined by substituting (25) in (24):

$$g_{1n} = 1.2\, g_{11} + 0.06(1.3333\, g_{21} + 0.8889\, g_{1n} - 35.5556) - 8$$

From this equation is found the final expression for determining the charge of the polymerization reactor:

$$g_{1n} = 1.2675\ g_{11} + 0.0845\ g_{21} - 10.7042 \quad (26)$$

Substituting (26) in (25) gives

$$g_{2n} = 1.3333\ g_{21} + 0.8889\ (1.2675\ g_{11} + 0.0845\ g_{21} - 10.7042) - 35.5556.$$

From this the final expression for the total charge of the reactor for alkylation of benzene by dodecylene is

$$g_{2n} = 1.1267\ g_{11} + 1.4084\ g_{21} = 45.0706 \quad (27)$$

For

$g_{11} = 100$ tons/day and $g_{21} = 100$ tons/day

From Equation (26)

$g_{1n} = 124.50$ tons/day

and from Equation (27)

$g_{2n} = 208.44$ tons/day

$g_{31} = 2\ g_{2n}a_{23} = 2.208.44 \times 0.55$
$= 1.1 \times 208.44 = 229.25$ tons/day

$$K_{R1n} = \frac{g_{1n}}{g_{11} + g_{21} + g_{31}} = \frac{124.50}{100 + 100 + 229.28} = \frac{124.50}{429.28} = 0.29002$$

$$K_{R2n} = \frac{208.44}{429.28} = 0.48556$$

According to (23) $g_{3n} = 3g_{2n}a_{23}$ and, therefore,

$$K_{R3n} = \frac{3\ g_{2n}a_{23}}{429.28} = \frac{343.93}{429.28} = 0.80118$$

Now that the recycling coefficients are known one can determine the total output of the entire complex of processes. The final outputs calculated on the basis of the sum of propane-propylene fraction, benzene, and sulfuric acid will be

Table 1

Compound	Yields of the once-through reaction in weight fractions: Polymerization of unrecycled stock	Alkylation	Sulfonation
Propylene	0.100 = P_1	a_{31} = 0.050	.....
Propane	0.400	.....	.....
Dodecylene	0.400 = P_2	.....	.....
Dodecylbenzene	.....	a_{32} = 0.550	.....
Benzene	.....	a_{33} = 0.250	.....
Alkylaryl sulfonate	.....	.....	0.40
By-products and losses	0.100 = P_3	0.150	0.09
Sulfuric acid (in its initial form)	.....	.....	0.51
Total	1.00	1.00	1.00

Propylene

$$a_{11} = \frac{(124.50 - 40)0.1}{0.6 \times 124.50} \approx 0.1131 \approx 11.31\%$$

$$\text{Propane} = \frac{40}{124.50} \approx 0.3213 \approx 32.13\%$$

Dodecylene

$$a_{12} = \frac{(124.50 - 40)0.4}{0.6 \times 124.50} \approx 0.4525 \approx 45.25\%$$

By-products and losses

$$\approx 0.1134 \approx 11.31\%$$

$$100\%$$

The recycling coefficients can now be determined.

First the quantity of sulfuric acid (g_{31}) is determined; it is to exceed by twofold that required by the hydrocarbon charge.

from polymerization:

Propane
$32.13 \times 0.29002 = 9.32\%$

By products and losses
$11.31 \times 0.29002 = 3.28\%$

from alkylation:

By products and losses
$15 \times 0.48556 = 7.28\%$

from sulfonation:

Alkylaryl sulfonate
$40 \times 0.80118 = 32.05\%$

By products
$9 \times 0.80118 = 7.21\%$

Sulfuric acid (without water)
$51 \times 0.80118 = 40.86\%$

100%

From these relative values the absolute quantity of each product may be calculated from the sum of fresh stock inputs of the several reactors ($g_{11} + g_{21} + g_{3n}$).

The same balance may be calculated on the basis of propylene and benzene only:

$$K'_{R1n} = \frac{g_{1n}}{g_{11}0.6 + g_{12}} = \frac{124.50}{160} = 0.77812$$

$$K'_{R2n} = \frac{g_{2n}}{160} = \frac{208.44}{160} = 1.30275$$

$$K'_{R3n} = \frac{g_{3n}}{160} = \frac{343.93}{160} = 2.14956$$

from polymerization:

Propane
$32.13 \times 0.77812 = 25.00\%$

By-products and losses
$11.31 \times 0.77812 = 8.80\%$

from alkylation:

By-products and losses
$15 \times 1.30275 = 19.54\%$

from sulfonation:

Alkylaryl sulfonate
$40 \times 2.14956 = 85.98\%$

By-products
$9 \times 2.14956 = 19.35\%$

Sulfuric acid (without water)
$51 \times 2.14956 = 109.63\%$

To check these results the quantity of arylalkyl sulfonate is determined in tons/day:

From the balance on an over-all reactant basis

$$\frac{32.05 \times 429.28}{100} = 137.58 \text{ tons/day.}$$

From the balance on the basis of the sum of propylene and benzene:

$$\frac{85.98 \times 160}{100} = 137.57 \text{ tons/day.}$$

The examples cited above show clearly that the system of equations (1) and formula (3) proposed gives an exact solution to problems associated with the material balance of complicated petroleum refining processes and of multistage organic syntheses. Applied to concrete problems the expressions assume a simple form and are solved without difficulty.

INVESTIGATING
CHEMICAL PLANT PROCESS VARIABLES

The accompanying paper describes an actual problem in the design of a pilot experiment encountered during operation. All the restrictions imposed are included and recommendations are made from a full factorial experimental design. Statistical interpretations are made through the analysis of variance technique. The example illustrates the type of over-all reasoning (mechanism and statistical) that many are applying to their experimentation.

Chemical engineers engaged in plant "trouble shooting" frequently find it necessary to design pilot experiments to solve a specific production problem. Many difficulties arise in planning such experiments, the number to be performed usually being limited. The planner finds that he must secure an answer to the problem quickly while seeking to assure that some degree of reliability can be attached to the conclusions. Experimental designs employing statistical methods are enjoying increasing acceptance in such applications. However, owing to the practical limits on experiments, the use of these statistical methdods aids in obtainng maximum information. Fortunately, interpretations through an understanding of the physical as well as the statistical system do lead to results that can be applied. Statistical interpretations in the problem described below were made through the analysis of variance technique (*1, 2, 3*).

The problem under investigation was of a twofold nature.

A current plant process had been examined in the research laboratories. An alternative method for producing intermediates was suggested. The claim was that this newer procedure would produce higher yields. At the same time the plant operating the existing process was having difficulties with one step of its operation, a catalytic hydrogenation. When called to "trouble shoot" the problem, the plant-service group explored the possibility of introducing the new process into the plant. There were drawbacks to this proposal. First, some changes in plant equipment would be necessary; hence, the new hydrogenation process could not relieve the present crisis. Second, the research studies were not executed in equipment that met engineering requirements for extrapolation to plant scale. Hence, there was a reluctance to accept the work as presented.

Organizing Problem

In view of these problems, a plan of investigation was suggested. First, experiments should be designed so that something could be understood about the present plant method that would serve as a clue to the production difficulties. Second, plant services should examine the new process and determine what factors or combination of factors make it superior to the present method. Finally, it should be determined whether one can combine the best factors in each process in such a fashion as to optimize the ratio of yield gain to equipment and installation charges.

As broad a plan as this was, it was urgent that data be made available quickly to set the plant back on stream. One set of experiments that would provide data on the three phases was needed. A statistically designed plan embodying a factorial design was selected as the means by which the results would be analyzed. Unfortunately, but as is usually the case in "trouble shooting" work, practical problems arose in setting up the pilot study.

The factors under investigation were qualitative in nature. Solvent, catalyst, and reactant of each process were to be compared by measuring quantitative factors, e.g., product yield. The solvents employed were different but chemically of a homologous series. Catalysts differed in the method of preparation; hence, surface properties could exhibit differences in the reaction. The reactants also differed because of the methods of preparation. Other factors, such as agitation, temperature, and grade of hydrogen (purity) were not varied. To carry out the experimental work, the plant laboratory had available a hydrogenator and a suitable experimental procedure.

The hydrogenator was dimensionally similar to the production unit and met all the chemical engineering requirements necessary for successful extrapolation to the plant. Experiments in this hydrogenator required that at least a gram-mole of reactant be charged per run to obtain reliable results. This condition determined the amount of material for each experiment and presented the first restriction to the number of experiments. The second restriction came as a result of the lack of material available from the new process. As a result of these

Table 1.—Results of Factorial Design

Treatment symbol	Grams product	% yield	Hydrogenation rate cc./min.	% theoretical H_2 absorbed
$S_1C_1R_1$	62.2	83.0	49.33	106.8
$S_1C_1R_2$	64.5	86.0	62.87	99.9
$S_1C_2R_1$	56.0	74.7	41.60	97.5
$S_1C_2R_2$	63.1	84.2	52.24	104.1
$S_2C_1R_1$	60.2	80.5	60.00	105.6
$S_2C_1R_2$	62.0	82.6	61.25	103.5
$S_2C_2R_1$	60.2	80.5	52.37	99.0
$S_2C_2R_2$	63.0	84.0	47.27	105.8

S = solvent
C = catalyst
R = reactant

$_1$ = existing process
$_2$ = new process

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two restrictions, only nine full experiments could be performed.

With these facts on hand, the introduction of the statistical design of experiments was planned. Since differences between factors and the possible advantage in combinations (e.g., interactions) of factors were being sought, a factorial design was most desirable. Embracing all possible combinations of the process variables would give maximum reliability and maximum coverage. It was recognized that with the full factorial of eight runs no replications would be possible and a rigorous statistical procedure would not be carried out. No independent estimate of error could be obtained and all factors would be examined with only one degree of freedom. As objectionable as this was, no other choice was available as the pressure of the plant crisis necessitated a pilot investigation even under these adverse conditions. A great effort was made to make estimates of the relationships between the variables with the anticipation that knowledge of the physical system would assist in the analysis.

Factor significance was to be determined at the 5% level. However, any factor significant at the 10% level that could be examined in the plant without significant changes was worth exploring. As an example, should the solvent be a significant variable, it could easily be introduced into plant operations and further experimentation carried on in the plant.

Process Variables

Chemically, the problem under consideration was a low-pressure catalytic hydrogenation of a double bond in the presence of other unsaturated bonds. The reaction was carried out in a solvent with a specially prepared catalyst. In this heterogeneous system agitation and temperature were important variables. However, since much work had been done previously in these areas to establish the optimum operating range, it was decided not to enter them into this series. The most significant dependent variable to measure was product yield. Certainly this is the result that would interest the production people the most. However, it was believed that differences in the independent variables could exhibit in other ways. Rate of hydrogenation and amount of hydrogen absorbed were included as dependent factors. The hydrogenation rate can be related to the properties of the catalyst and the solvent. Selection of a catalyst offering a high gas uptake would be important to the plant, as it would influence production time cycles. In addition, data on catalysts would aid in future developments on the process. The amount of hydrogen absorbed, of course, is related to product yield. In the complicated chemical system studied here, hydrogenation absorbed is also an indication of reactant and product quality, that is, it serves to indicate the presence of other hydrogenated materials.

Experimental Procedure

The pilot process consisted of adding a weighed sample of reactant and catalyst to a known volume of solvent in the agitated hydrogenation vessel. The mixture was brought to the proper temperature, and hydrogen fed into the mixture below the surface of the liquid. The volume of gas was read from a calibrated cylinder by its displacement with water. When the rate of hydrogen uptake stopped or remained at a constant low value, the gas introduction was stopped and the product isolated. Isolation required filtration and removal of catalyst followed by crystallization, filtration, and drying of the product. For every run the same vessel, agitator, agitator speed, and isolation equipment was employed.

Statistical Analysis
F Ratio Tests

Eight experiments were performed in a random order and are tabulated in Table 1.

Table 2 summarizes the analysis of variance data with product yield as the dependent variable. The sum of squares calculations were carried out by the methods illustrated in (*1, 3*). It is observed that the main effects are not significant when compared with the residual. If any term is important, it would be the $C \times R$ interaction. Significance can be determined by the F ratio test.

$$F_{1,1} = \frac{24.69}{2.79} = 8.9$$

This interaction then is significant at the 20% level, or there is a one in five chance of being wrong, certainly not within the desired 5-10% significance level. If all other factors are nonsignificant, the mean squares can be pooled with the residual and a new estimate can be obtained of the error (residual) with six degrees of freedom (*3*).

$$\frac{\text{pooled mean squares}}{\text{degrees of freedom}}$$

$$= \frac{23.41}{6} = 3.9$$

Calculate F at $F_{1,6} = \frac{24.69}{3.9} = 6.32$

Expected value of F at 5% significance level = 6.00

Table 2.—Analysis of Variance Data With Yield (Product Weight) As Dependent Variable

Source of variance	D.F.	Sum of squares	Mean squares
Between *S*	1	0.02	0.02
Between *R*	1	4.20	4.20
Between *C*	1	5.44	5.44
$S \times R$ interaction	1	1.81	1.81
$C \times R$ interaction	1	24.69	24.69
$C \times S$ interaction	1	9.15	9.15
Residual	1	2.79	2.79
Total		48.10	

Table 3.—Analysis of Variance Data With Hydrogenation Rate As Dependent Variable

Source of variance	D.F.	Sum of squares	Mean squares
Between S	1	31.402	31.402
Between R	1	8.507	8.507
Between C	1	209.817	209.817
$S \times R$ interaction	1	0.652	0.652
$C \times R$ interaction	1	46.700	46.700
$C \times S$ interaction	1	2.258	2.258
Residual	1	115.439	115.439
Total		414.775	

Then a $C \times R$ interaction is indicated.

However, this method of indiscriminate pooling of treatment mean squares is not completely reliable (*2*). A logical procedure is to decide what factors may be small and possibly can be ignored. This entails a theoretical knowledge of the system under investigation. These factors may be pooled to give an estimate of the error term. In this experiment, it was initially believed that little or no difference would result between the solvents. Both were similar in all properties except boiling point, and the only purpose was to serve as the heat-transfer media and dispersant for catalyst and reactant. Hence, it was felt that all mean squares containing S factors could be pooled on sound theoretical considerations. The $C \times R$ interaction could then be tested against this new estimate of the error.

Pooling Factors

$$\text{Mean square} = \frac{13.77}{4} = 3.44$$

$$F_{1,4} = \frac{24.69}{3.44} = 7.17$$

Expected value of

$F_{5\%} = 7.71$

$F_{10\%} = 4.54$

The significance of the $C \times R$ interaction is near the 5% level but certainly better than 10%.

Experiment $S_1C_2R_2$ (Table 1) appears to be out of line both experimentally and statistically. The yield result differs from the others by more than the 2σ limit. Experimentally some difficulty was encountered during the latter part of the isolation which could have accounted for a yield loss. The other dependent variables were believed to be completely reliable. With this basis, the question arose as to whether a $C \times R$ interaction would appear with the other dependent variables or could significant C and R's be determined. An analysis of variance was performed with (*1*) hydrogenation rate and (*2*) per cent theoretical hydrogen absorbed as dependent variables. Tables 3 and 4 respectively summarize the calculations.

Table 3 is the analysis of variance table when rate of hydrogenation is the dependent variable. It appears that all factors except the "Between C" are not significant. With the use of the F ratio test all terms except the "Between C" were combined to give a residual error term of 34.159 with six degrees of freedom. The F test (Between C)

$$F_{1,6} = \frac{209.817}{34.159} = 6.16$$

and the expected value of $F_{1,5}$ at the 5% level is 6.00.

Again, pooling "S" factors would give a more reliable estimate of the error term.

Table 4.—Analysis of Variance Data With % Theoretical Hydrogen Absorbed as Dependent Variable

Source of variance	D.F.	Sum of squares	Mean squares
Between S	1	3.91	3.91
Between R	1	62.71	62.71
Between C	1	10.93	10.93
$S \times R$ interaction	1	2.66	2.66
$C \times R$ interaction	1	2.54	2.54
$C \times S$ interaction	1	0.20	0.20
Residual	1	3.00	3.00
Total		85.95	

POOLING S VALUES

$$F_{1,4} = \frac{209.817}{37.437} = 5.604$$

Expected $F_{10\%} = 4.54$

The conclusion is that when rate of hydrogenation is the dependent variable there is a difference between catalysts. This difference is significant at the 10% level of significance. From Table 1 the mean values of hydrogenation rate are found to be

$C_1 = 58.61$ cc./min.
$C_2 = 48.37$ cc./min.

The hydrogen absorbed results (Table 4) show only one probable significant variable, the R term. Six terms were pooled here to measure the significance of the "Between R" term.

BETWEEN R

$$F_{1,6} = \frac{62.71}{3.87} = 16.4$$

significant at the 5% level as $F_{1,6} = 6.0$. Again, from Table 1 the mean values of the per cent theoretical hydrogen absorbed was found to be:

$R_1 = 105.57\%$
$R_2 = 100.00\%$

Pooling S values, as was done under the two previous tables, the new estimate of residual error mean squares is 62.71 and the F test

$$F_{1,4} = \frac{62.71}{2.44} = 25.6$$

The expected value of $F_{1,4}$ at the 5% level is 7.71. The difference between the R factors is statistically significant.

Conclusion

With the aid of the three variance tables, a conclusion can be drawn about the materials from the two processes. First, no significance was noted between the solvents. This was the anticipated result. The solvents were very close in physical and chemical properties and served only to provide intimate mixing between the phases. Results obtained with C and R were surprising. Little work had been done on the preparation of the catalyst and these experiments were literally the first comparison made on this material. The fact that a difference existed between reactants could not be explained as such.

However, the appearance of an interaction between C and R factors was interesting. The normal plant yield (condition $S_1C_1R_1$) was 80% with $\sigma = 1.2$. Examining the $C \times R$ values

of yield, one observes that they are opposing each other. That is

	R_1	R_2
C_1	81.75	84.30
C_2	84.10	78.70

Hence to specify an R value, a C value must also be specified. Now when the results with the other process variations are included, one desires an explanation of the significance of C and R alone. C_1 produces the high rate of hydrogenation and R_1 the higher percentage of theoretical hydrogen absorbed; but, together, nothing of importance occurs. The experimenter explains this very simply. Since this compound has more than one unsaturated position, it is possible for it to add hydrogen in other than the position desired. Conceivably then, overhydrogenation can result in a decrease in yield of the desired compound. Data here indicate that proper hydrogenation is related to both catalyst type and some particular property of the reactant (which was not determined). It appears that the plant could make improvements over its present 80% yield by incorporating these favorable combinations. However, the possibility of utilizing the indication of overhydrogenation was something that could be applied at once. Consequently factory hydrogenations were run until 100% of the theoretical hydrogenation was absorbed. Results were gratifying as a 2 to 2.5% yield increase was obtained.

It should be noted here that the general selection of significance levels and the pooling of effects must be used and interpreted with discretion. The result of any test depends on the size of the random error; hence, sufficient experimental work should be available to estimate this error. With limited data, the experimenter must have a clear understanding of the risks involved when attempting to make decisions. The dangers of selecting nonsignificant factors or missing significant ones is always present. Cases, such as the one described herein, that may involve expensive plant additions, should have the benefit of additional data to substantiate the initial conclusions after the first crisis has passed.

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SYNTHETIC FIBERS — THE FUTURE

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The true synthetic fiber industry dates from the introduction of nylon to the textile market just prior to World War II, and has had a phenomenal rate of growth—from 10 million pounds in 1940 to nearly 500 million pounds in 1956.

Prediction: The use of synthetic fibers for all purposes will increase to 1.1 billion pounds by 1965, to 4 billion pounds by 1975 (see Figure 1).

An indication of the confidence of industry in the future of synthetic fibers is shown by a recent compilation listing the names of some 800 semisynthetic fibers in various stages of development or production throughout the world. Some recently announced in this country: Creslan, Darlan, Zefran, I.R.C. nylon and Verel. Cyanamid's Creslan plant will be located at Pensacola, Fla.; Dow's Zefran plant is under construction near Jamestown, Va.; Eastman's Verel fiber is being produced at Kingsport, Tenn.; the location of Goodrich's Darlan plant and Industrial Rayon's I.R.C. nylon plant have yet to be announced. In addition, substantially all established fiber plants are now being expanded.

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Fibers and Fabrics

In evaluating the future potential for synthetic fibers, the requirements for the major end uses must be kept in mind. In the apparel field, aesthetic qualities and styling are generally more important than utility. Blends of synthetic fibers with cellulosic or natural fibers are widely employed to obtain desired surface or other characteristics, and fabric designing, dyeing, and finishing are important considerations. The present emphasis on ease of living is accelerating the development of wash-and-wear fabrics. The wrinkle resistance and crease retention properties of many of the synthetic fibers make them of particular interest to the apparel field.

Fibers purchased for industrial applications are chosen mainly from the standpoint of physical properties and price. Tensile strength, softening point, chemical resistance, and wearing qualities are important.

Synthetic fibers generally have excellent mechanical properties, but they are hydrophobic and thermoplastic. The first property promotes the development of static electricity and may make dyeing difficult, but it improves

resistance to soiling and launderability. The thermoplasticity of synthetic fibers makes it easy to impart permanent pleats and creases to synthetic fabrics, but it may also result in glazing in 100% synthetic fabrics.

Other problems associated with synthetic fibers are pilling, fibrillation, and dyeing. Pilling results when a broken strand of fiber curls into a ball on a fabric because of wear and does not break off because of the fiber's strength. It is usually controlled by proper fiber blending. Fibrillation results when small strands along a single filament break away and form a white powder, masking the color of the fabric. It may be readily controlled by proper orientation of the fiber during the manufacturing process. Dyeing problems generally are solved by the incorporation of dye acceptors in the polymer, such as in the acrylics, or by the use of dyeing assistants, as in the case of the polyester fibers.

Table 1.—Important New Developments

- I. New fiber raw materials
  - (1) Isotactic polymers
  - (2) Vinyl cyanide and tetrafluoroethylene polymers
- II. New processes
  - (1) Polymerization
    - (a) Isotactic polymerization
    - (b) Graft polymerization
    - (c) Radiation polymerization
  - (2) Spinning
    - (a) Emulsion sintering
    - (b) Spray and draw techniques
  - (3) Yarn and spinning techniques
    - (a) Textured yarns
    - (b) Bulked yarns
    - (c) Direct spinning

The development of commercially acceptable procedures for the elimination of the problems associated with the use of synthetic fibers in the textile and related fields in recent years is leading to a rapid upsurge of interest in such fibers on the part of the textile processor and the consumer. Further improvements are in sight.

These developments are of profound importance from the standpoint of assuring the increasing use of established fibers in established end uses. They are based on procedures that have been developed during the past decade.

New Developments

Other developments of the past two or three years are of equal, or greater, importance in widening the field of utilization of synthetic fibers. A representative series of such developments is listed in Table 1.

ISOTACTIC POLYMERS

It has long been known that the simple vinyl compounds, such as ethylene and propylene, can be readily converted to polymers which can be spun to form fibers. However, the relatively low melting points and low tensile strengths of such fibers have greatly restricted their use in the textile and other fiber fields.

A development of great importance in the fiber polymer field has been the discovery of procedures by which vinyl compounds, including the simple olefins such as ethylene and propylene, can be converted to symmetrical polymers of greatly improved crystallinity. These polymers are known as isotactic polymers, and they can be spun into fibers having very good mechanical and thermal properties. The processes for the production of isotactic polymers were developed mainly by Schildknecht and Alfrey in this country, Ziegler in Germany, and Natta in Italy.

The process involves the use of certain catalysts, known as stereo-specific catalysts, and the polymer molecule grows on the catalyst surface to form long straight chains. A number of different catalyst systems have been proposed, of which the following may be considered to be representative:

(1) An aluminum alkyl + titanium chloride
(2) Lithium alkyl which may be supported
(3) Alfin catalyst (sodium alkyl, sodium alkoxide, sodium chloride)
(4) Certain hydroforming catalysts

The polymerization proceeds to form long, threadlike polymers substantially free from branching. They are related structurally to the stereo (DL) forms of certain organic compounds possessing optically active carbons in the chain. Thus, in the case of the isotactic propylene polymer, the methyl groups are all located on the same side of the polymer chain, giving a highly crystalline character to the molecule. This contrasts with the amorphous nature of polyisopropylene produced by more conventional methods.

The implications of this procedure are of great importance to the fiber technologist because it affords the opportunity of making strong, high melting fibers from relatively inexpensive and readily available raw materials. As a result, a substantial amount of work is being carried out in this country and abroad on the production of polyethylene, polyisopropylene, and polystyrene fibers from the corresponding isotactic polymers. While many problems remain to be solved, particularly in spinning operations, it is to be expected that a number of industrially important fibers will be developed as a result of this new concept in the polymer field.

OTHER POLYMERS

In addition to the provision of new polymer types made from simple aliphatic and aromatic olefins by the isotactic polymerization procedure, other new polymers have been added to the list of those available to the fiber technologist. These include the vinylidene cyanide polymers developed by Goodrich and the tetrafluoroethylene polymers developed by Du Pont. Fibers spun from the former polymers possess a very soft and lofty hand,* while the Teflon fibers obtained from the latter have very good thermal and chemical resistant properties.

Isotactic polymerization methods may be used to give improved polymers from monomers already well established in the synthetic fiber field, as well as to provide polymers from new raw materials. The work on the production of isotactic olefin polymers has been closely paralleled by intensive work on the use of isotactic polymerization methods to modify the properties of polymers now being used for the production of synthetic fibers. This work may ultimately prove to be equally as valuable as the provision of new polymer types from monomers previously not considered for this purpose.

BLOCK AND GRAFT COPOLYMERS

Another fundamental development in the polymer field, and one of particular importance to the fiber chemist, has been the synthesis of block and graft copolymers. Whereas binary copolymers of monomers A and B may have either ordered

—A BA BA BA BA BA B— (1)

or random

—A BBA BB BBAA AA B— (2)

configurations, block copolymers of A and B contain long alternating stretches of A and B:

—50A—50B—50A—50B— (3)

while graft copolymers prepared from the same monomers contain blocks of one of the monomers as a backbone, with branches made up of blocks from the other monomer:

```
      50B  50B  50B
       |    |    |
—50A—50A—50A—        (4)
```

It is immediately apparent that the configurations of copolymers (1) and (2) are essentially different from those

* "Hand" is the "feel," the texture of a fabric. "Lofty" means springy, fleecy, with body like wool.

of copolymers (3) and (4), and that such differences are of sufficient magnitude to impart radically different properties to the latter two copolymers, and to the fibers subsequently obtained from them. This has been verified experimentally, thus opening up a new avenue of approach to the production of acrylic, vinyl, and other fibers possessing entirely new physical and chemical properties.

In ordered or random copolymers, the blending of the two constituents is very intimate in nature, the change from A to B occurring on a micromolecular scale. As a result, the properties of such copolymers are essentially an average of the corresponding properties of the two components. Thus, if A is an oil-soluble monomer, such as vinyl alcohol, the resulting regular or random copolymer will be soluble in solvents of intermediate polarity, such as dioxane.

Block and graft copolymers, on the other hand, represent a much coarser mixture of components A and B than are obtained in ordered or random copolymers. The individual sequences, or blocks, of A and B display to a certain extent some of the characteristics of the corresponding homopolymers of A and B. As a consequence, certain properties of the copolymers of Type 3 and Type 4 should represent a superposition of the properties of polymer A and polymer B rather than an average of such properties.

Results have tended to confirm this hypothesis. Thus, a graft copolymer of styrene and vinyl alcohol containing a backbone of 500 styrene units and 20 branches of 25 vinyl alcohol units each is soluble in both water and toluene. In water, the polyvinylalcohol branches are readily dissolved or solvated, with the result that the insoluble polystyrene segment, being chemically linked to the solvated or dissolved polyvinylalcohol units, is maintained in a state of stable suspension.

If the same copolymer is placed in toluene, the polystyrene trunk is readily dissolved, while the polyvinylalcohol branches collapse on each other and are maintained in a state of stable suspension due to their chemical attachment to the dissolved polystyrene trunk.

Thus, in either of the two solvents listed, one half of the graft copolymer may be regarded as being dissolved, while the other is precipitated. In a liquid which is a solvent for both components, however, such as a mixture of water, dimethylformamide, and toluene, all segments of the polymer, both trunk and branches, are solvated and the entire polymer is dissolved.

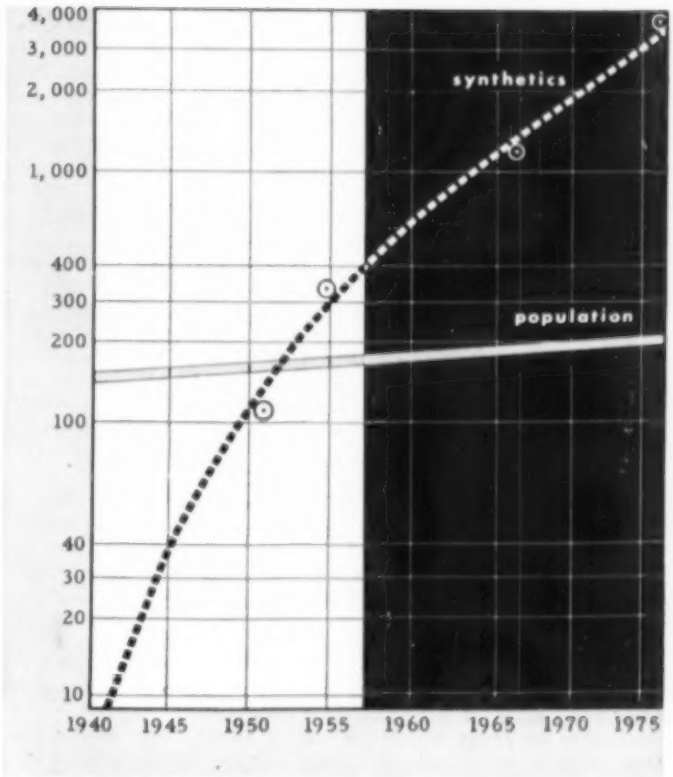


Fig. 1. Total U. S. synthetic fibers (millions of pounds) and population (millions).

FORMING BLOCK COPOLYMERS

Block copolymers may be obtained in a two-step operation involving the preliminary preparation of Polymer A and Polymer B in separate reactions in such a way that each contains reactive groups at both ends, followed by combining the two fractions and continuing the polymerization in the presence of a suitable bifunctional linking agent. The blocks of Polymer A and Polymer B are then connected and form a polymer containing the desired sequence of Polymer A and Polymer B units, the actual composition being regulated by the polymerizing conditions employed in each step of the operation.

As an example, the polymerization of styrene at low temperatures with hydrogen peroxide and ferrous sulfate results in linear polystyrene molecules having an hydroxyl group at each end. By the use of appropriate concentrations of styrene, catalyst, and activator, the number of styrene units in the polystyrene blocks can be regulated at will. Polymethacrylate blocks then are prepared in a similar manner, after which the two are mixed and linked together with a diisocyanate to form a linear block copolymer.

FORMING GRAFT COPOLYMERS

Two general methods have been used to form graft copolymers. In the first, polystyrene is prepared and lightly oxidized to form a series of —OOH groups dispersed in an essentially random fashion along the polystyrene chain. Vinyl alcohol is then added, together with a redox activator, such as ferrous gluconate. The ferrous ions react with the hydroperoxyl groups to produce free radicals, which are all attached to the polystyrene trunk. As a result, the polymerization of the vinyl alcohol is restricted entirely to the formation of polyvinylalcohol branches on the polystyrene backbone. Other monomers can, of course, be used in place of styrene and vinyl alcohol to give a variety of graft copolymers.

As an example of the second pro-

cedure, a copolymer of styrene and from 1 to 2 mole % of vinylacetate is prepared in methylethyl ketone solution. Due to the difference in relative reactivity of the two monomers, the vinylacetate units are isolated and attached at widely spaced intervals along the polystyrene chain. The acetate then is hydrolyzed to form hydroxyl groups, followed by the addition of ethylene oxide and a continuation of the polymerization. Under these conditions, all of the ethylene units are attached as chains to the polystyrene trunk. As in the preceding procedure, a wide variety of graft copolymers can be prepared by this method.

The development of block and graft copolymers is of outstanding importance to the fiber chemist in the acrylic and vinyl fields. Thus, for example, the desirable properties of the vinyl fibers have recommended their use in many apparel applications, but certain limitations of the fibers with respect to dyeing and static problems have retarded their use in certain fields. These difficulties have been met, in most part, by the preparation of copolymers and their use as such, or, in admixture with other polymers or copolymers, to prepare fibers having improved dyeing and static characteristics. The graft and block technique will make it possible to modify the fibers even further in these and other respects to an extent which has not been possible heretofore. A whole new spectrum of fibers possessing outstanding properties for use in certain specific applications should result, thus bringing nearer the day when fibers can be tailored to fit definite end uses.

RADIATION AND POLYMERIZATION

Another new development is the use of radiation of different types to influence the course of the polymerization, usually resulting in some degree of cross-linking of the polymer chains. Under carefully controlled conditions, polyethylene prepared by radiation polymerization procedures will give fibers with improved thermal resistance and strength, with a corresponding reduction in elasticity and solubility. It is evident that this procedure offers the possibility of making an entirely new series of fiber types having many applications, particularly in the industrial field.

SPINNING, DYEING, AND FINISHING

Recently, Du Pont was confronted with the problem of spinning polytetrafluoroethylene, for which no suitable solvent was known and which was not sufficiently plasticized with heat for melt spinning purposes. A procedure was finally developed which involved preparing an emulsion of finely divided polymer, pumping through a spinnerette, and fusing the particles to form a continuous fiber by the application of heat.

This fourth spinning process, which is basically different from the classical wet, dry, and melt spinning techniques, may be called emulsion sintering spinning. It provides a method for spinning a number of intractable polymers which cannot be handled by other procedures, thus making available a new series of high-softening, chemically resistant fibers.

A substantial amount of work has been carried out by different companies on various spray and draw techniques for the production of synthetic fibers without using spinnerettes. In one such procedure, developed by Dow, dopes or melts are drawn into fibers by dispersion on countercurrent cylinders. In a recent method developed by American Viscose, dopes or melts are sprayed into a current of heated air or gas, resulting in the production of microfibers which are of irregular length and small in size (0.2 denier or less). The microfibers can be combined with more conventional fibers during the spinning process, if desired, and the procedure offers many interesting possibilities to the fiber technologist.

Dope dyeing, in which the dye or pigment is incorporated into the dope or melt prior to the spinning operation, is assuming greater importance in the synthetic fiber field. Dyed fibers can be obtained at less cost and with greater color fastness than by conventional dyeing procedures, but the large number of colors required by the textile trade has retarded developments in this field somewhat.

Improved antistatic finishes are being developed for several synthetic fibers, and a substantial amount of work is being carried out on the development of permanent antistatic characteristics by the incorporation of hydrophilic ingredients into the fiber molecule prior to spinning. The graft and block techniques should be of substantial assistance in this undertaking.

Market Future

A number of important uses for synthetic fabrics are developing or growing. Pile fabrics have already made a permanent place for themselves in the synthetic fur and fleece field, where the potential market is some 100 million pounds a year.

Another major field of potential expansion is the use of synthetic fibers as reinforcing agents and fillers for plastics, and a third potentially large market, estimated to be nearly 70 million pounds a year, is in the fabrication of tarpaulins and tents where the use of nylon results in substantial savings in weight. The experiment of inflatable buildings made from plastic or rubber-coated synthetic fibers offers an almost unlimited field for expansion. (A Chicago hardware firm is already operating an experimental store in a collapsible building supported by mild air pressure, and in New York an "air house" designed by Frank Lloyd Wright has been on display.)

Collapsible tanks and containers for the storage of solids, liquids, and gases are now being manufactured by a number of companies.

A new suspension system for automobiles, based on compressed air and a coated synthetic fabric bellows as a suspending and shock absorbing member, has been in use on trucks and buses for several years, and will be used on passenger cars in the near future.

These, of course, are only a very small part of the potential markets for synthetic fibers, but they emphasize the versatility of the fibers. From an over-all standpoint, the continued improvement of synthetic fibers will result in their expanding use in the textile field and the industrial field.

Condensed from a paper presented at A.I.Ch.E. meeting, White Sulphur Springs, West Virginia.

CORRECTION

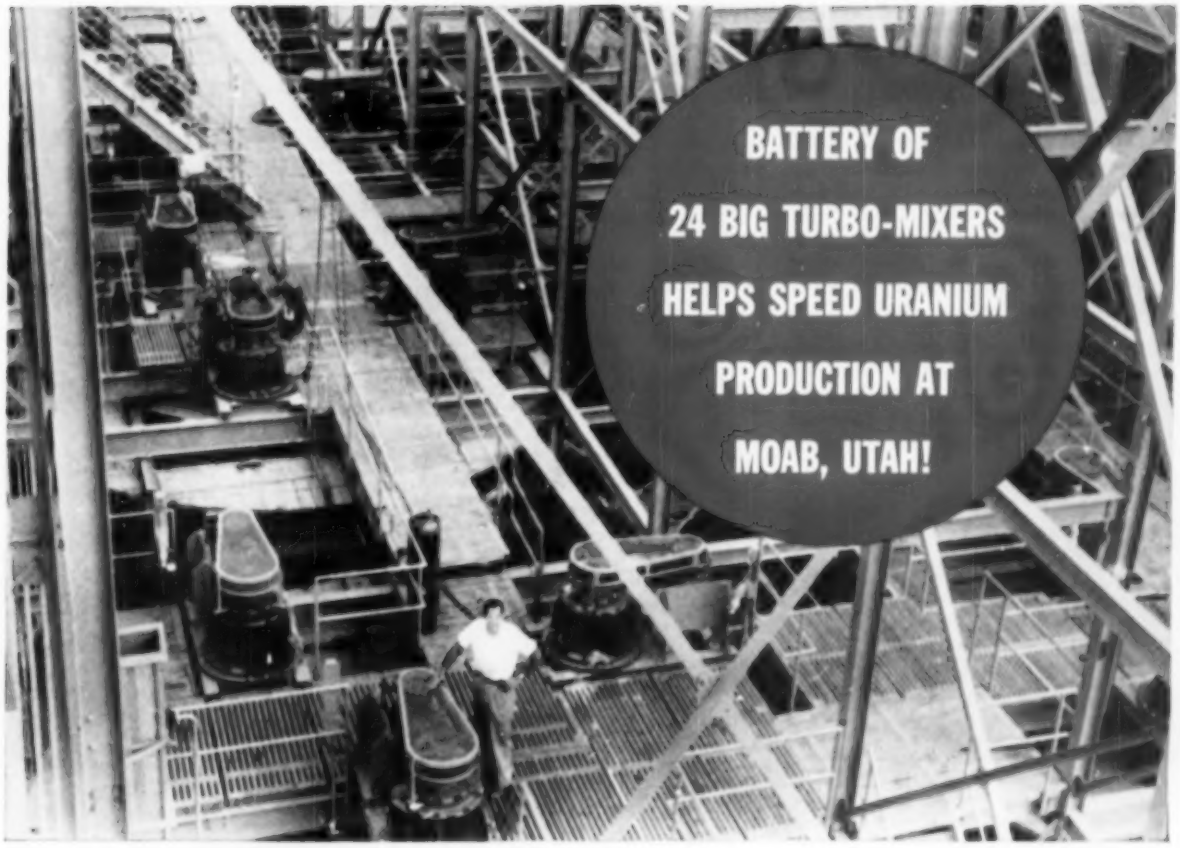
In "Oxide Fuel Elements for High Temperatures" by J. H. Handwerk and R. A. Noland (C.E.P., February, 1957, page 60-F), the following should be changed:

On page 60-F Mr. Noland's title should be Metallurgical Engineer.

On page 62-F the paragraph starting with "The fuel subassembly . . ." has been clarified to read: "The fuel subassembly for Borax-IV consists of six tube plates of aluminum-nickel alloy (1 w/o Ni in 2S aluminum, 8 tubes/tube-plate) spot welded into an assembly as shown in Figure 7. The fuel charge consists of 24 in. of uraniathoria pellets lead bonded in place in each tube plate.

The diameters of the fired pellets should be $0.229 \pm .002$ in.

In the Acknowledgment the name of J. M. Allan, whose help was appreciated by the authors, should be included.



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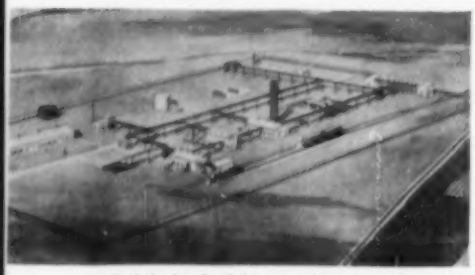
BOOM IN BORON CHEMICALS AND FUELS

Callery Chemical, already constructing its giant high-energy boron fuel plant, will build a second plant to produce specialty boron chemicals for commercial use. New Callery plant will also be capable of producing the high energy fuels.

Olin-Mathieson Chemical has revealed that it too is building a $36 million plant to make high energy boron fuels on contract for the Air Force. Names raw materials.



Artist's sketch of the new plant shows the eleven buildings and four process areas, shows similarities to Callery's first plant at Muskogee where high-energy fuels are being produced for the Navy.

A second boron chemicals plant to be built by Callery will be a $3 to $4 million specialty boron chemicals plant (sodium borohydride, trimethoxyboroxine, "TMB," amine boranes, potassium borohydride, methyl borate, etc.) at Lawrence, Kan. The new plant will consist of 11 buildings and four chemical processing areas, is said to be "the world's first fully integrated plant for the commercial production of specialty boron chemicals." Products of the plant will be sold to private consumers, the plant will be financed completely by private capital.

Contract for design, procurement, and construction of the new Callery plant has been awarded to Chemical Plants Division of Blaw-Knox. Work started late in May.

Fuels—Raw Materials

The spotlight is still on the revolutionary high-energy boron fuels, however, since Callery's new plant will also be capable of producing fuels and fuel intermediates (diborane, pentaborane, decaborane), and Olin Mathieson has just confirmed that its under-construction plant at Model City, N. Y. is a $36 million borane fuels plant for the Air Force.

In revealing that the products of its new plant will be the high-energy boron fuels, Olin Mathieson explained that the starting materials are boron, lithium, and fluorine. In the process, lithium hydride is reacted with boron trifluoride etherate to yield diborane. The seven major derivatives of diborane, including pentaborane and decaborane, are obtained by applying heat to the diborane under the proper process conditions. In comparing the high-energy fuels to conventional fuels, Olin Mathieson explained that diborane delivers 32,000 B.t.u. a pound, pentaborane and tetraborane give 30,000, and decaborane gives 26,000. This is compared to JP-4 jet fuel at 20,000 B.t.u. a pound.

Production of decaborane, high-energy compound of boron and hydrogen, has begun at the Henderson, Nev., pilot plant of American Potash & Chemical Corp. The company says that while most of the plant's output is being used to meet existing sales commitments, limited quantities of decaborane are available to industry for investigational purposes. □

GOODRICH DENIES JUSTICE DEPARTMENT SUIT

B. F. Goodrich Co. rejects and will fight the Justice Dept.'s claim that the company should turn over to the Government the Goodrich-Gulf process for duplicating the natural rubber molecule.

In filing suit recently in Washington, D.C. against Goodrich, the Justice Dept. says that Goodrich was using Government funds granted for research in the synthetic rubber field when the discovery of its Ameripol SN "natural" rubber process was made. The Government is asking the Federal Court to order Goodrich to turn over all information on the Ameripol SN process so the Government can make it available to the entire rubber industry.

Goodrich flatly denies the claim. "The discovery of Ameripol SN rubber was a development of Goodrich-Gulf Chemicals, Inc., and bore no relationship whatsoever to a research contract between the B. F. Goodrich Co. and the Government. The discovery which the Government now seeks to take away from B. F. Goodrich was based upon scientific knowledge purchased by Goodrich-Gulf in Europe in 1954."

The Justice Dept., on the other hand, claims that B. F. Goodrich received $1,705,400 in Federal research funds from 1949 to 1955, and agreed to reveal to the Federal Government all information developed during those years.

But Goodrich contends that, "the discovery was made with the private funds of Goodrich-Gulf Chemicals, not by B. F. Goodrich, and SN rubber is the property of Goodrich-Gulf Chemicals, Inc." And, Goodrich insists, "there is no justification whatsoever for the Government's claim."

Goodrich further claims that the Government is making no charge that its funds were used for the development of this particular process, but only that when the development took place Goodrich was receiving Government funds.

In opposition to these contentions of Goodrich, the Government in its suit has cited the terms of its contract with Goodrich to this effect: "The contract provided that the Goodrich Co. would conduct research as to the principles governing the preparation of rubber-like polymers of butadiene and its hydrocarbon homologues and would make available to the Government all information within the scope of such research acquired from any source by the Goodrich Co. or its subsidiaries regardless of whether such information resulted from research paid for by the Government."

"The contract further provided," alleges the Government suit, "that the Government would be granted a royalty-free license of such information, and the right to make it available to other companies."

Multi-million pentaerythritol plant of Hercules at Louisiana, Mo., is now on stream. The new facilities are designed for production of 24 million pounds of pentaerythritol and 100 million pounds of formaldehyde annually. A unit designed to produce 70 tons per day of methanol is scheduled for subsequent completion. The complex of plants will permit Hercules to produce pentaerythritol starting with natural gas and steam, the basic ingredients for the production of methanol. □

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INDUSTRIAL NEWS

A major, long-term, multi-million-dollar expansion program involving complete relocation of several plants is underway at J. Bishop & Co. Platinum Works, Malvern, Pa. Manufacturing divisions and offices will be centralized at an East Whiteland location, four miles west of Paoli, Pa. □

Construction will start in July, 1957, on a new addition to the Foxboro Company's instrument manufacturing plant at Foxboro, Mass. Completion of the new addition, scheduled for early summer of 1958, is expected to increase the firm's production capacity by approximately fifty per cent. □

A new company, California Chemical Company, will consolidate the chemical activities of Standard Oil Co. of Calif. The new organization will coordinate activities of two presently existing subsidiaries, California Spray-Chemical Corp., manufacturer and marketer of agricultural chemicals, and Oronite Chemical Co., which functions in the field of industrial chemicals. □

Startup of new $3,000,000 phthalic anhydride facilities by Pittsburgh Coke & Chemical's Industrial Chemicals Division near Pittsburgh will double the company's phthalic anhydride capacity. The new facilities were designed and built by the Lummus Co. □

Spencer Chemical will increase capacity of their polyethylene facilities at Orange, Texas, from 45 million to 90 million pounds per year. The new facilities will produce conventional and medium density polyethylene by the same high pressure process employed since the plant started in 1955. □

A contract to modernize and expand Food Machinery and Chemical Corp.'s carbon tetrachloride plant at South Charleston, W. Va., has been awarded to Fluor Corp. Completion of construction is expected early in 1958, will approximately double production. □

A plant for manufacturing silicone consumer products is being built at Greensboro, N. C., by Dow Corning. □

Sinking of a shaft for a new potash mine will be started immediately by International Minerals and Chemical Corp. Site of the new mine, said to contain ample reserves, is in the Canadian province of Saskatchewan. □

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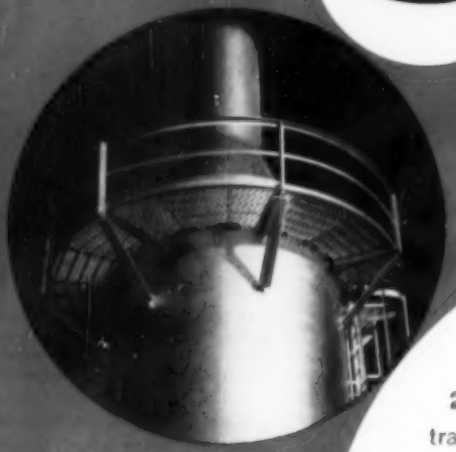

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THREE NEW ETHYLENE OXIDE PLANTS WILL PRODUCE 180 MILLION POUNDS

The Lummus Co. is now building three large ethylene oxide plants, the first commercial plants to make use of Shell Development's direct oxidation process. The three plants are:

- **Wyandotte Chemical's near Baton Rouge, La.**
- **Calcasieu Chemical Corp.'s at Lake Charles, La.**
- **Petroleum Chemicals Ltd.'s plant at Partington, England.**

Representing major expansions in ethylene oxide and ethylene glycol facilities (60 million pounds of ethylene oxide at each plant), as well as the first commercial applications of Shell Development's new direct oxidation process, the three plants being designed and engineered by Lummus are expected to demonstrate the advantages of the Shell process which are said to include high yields and the virtual elimination of waste disposal problems encountered in the chlorohydrin process.

At Wyandotte Chemical's facilities at Geismer, La. near Baton Rouge, most of the high purity ethylene oxide produced will be converted by thermal hydration to ethylene glycol in the facilities provided for this purpose at the plant.

Calcasieu Chemical's installation at Lake Charles will also have an ethylene glycol section, will get its ethylene from Petroleum Chemicals, Inc. The English plant of Petroleum Chemicals Ltd., one of the Royal Dutch Shell group companies, does not include a glycol section, is not going into glycol production.

All three plants should be on stream by mid-1958.

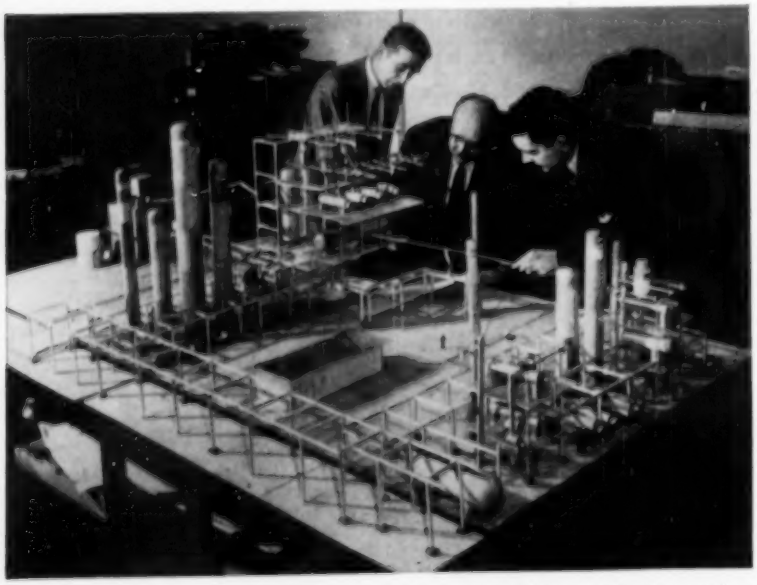
The Process

Shell's process, now thoroughly tested in pilot plant stage, is a direct catalytic oxidation of ethylene with oxygen in fixed bed reactors over a silver catalyst. Air could be used in the process, but oxygen is more economical, and the three plants will use oxygen, presumably produced from air in an oxygen section at the plant sites. Capital investment is considerably lower when oxygen is used.

After formation of the ethylene oxide in the reactor sections of the plants, it is purified by absorption in water, is depressured, distilled, and dried. (Some glycol invariably will form during this operation.)

Yield factors in the process, based on 98% ethylene and 95% oxygen, are said to be 1.1 pounds of ethylene for each pound of ethylene oxide; 1.810 pounds of oxygen for each pound of ethylene oxide; and 0.753 pounds of ethylene oxide per pound of ethylene glycol.

The ethylene glycol step used in the Shell process is thermal hydration of ethylene oxide at elevated temperatures and pressure with a special catalyst.



Lummus engineers, the designers and builders of all three new ethylene oxide plants, study a scale model of Wyandotte Chemical's new facility expected to be on stream before mid-1958.

MAJOR EXPANSION AT FORMER GOVERNMENT SYNTHETIC PLANT

At the former Government-owned synthetic rubber plant in Houston, Goodyear Tire and Rubber has just completed a 50% expansion at a cost of $10 million.

Completion of a production capacity boost of Goodyear's Plioflex rubbers has brought total production at the Houston plant to 220,000 long tons a year. This makes the plant the world's largest single producer of dry type synthetic rubbers.

Each of these new reactor lines contains eleven 5,000-gallon reactors. The three stripping towers of the recovery area tower above the new reactor building of Goodyear's plant.

Completion of the expansion came just two years after Goodyear purchased the plant from the Government, and the company feels it is indicative of the progress made by private ownership and operation of the plant.

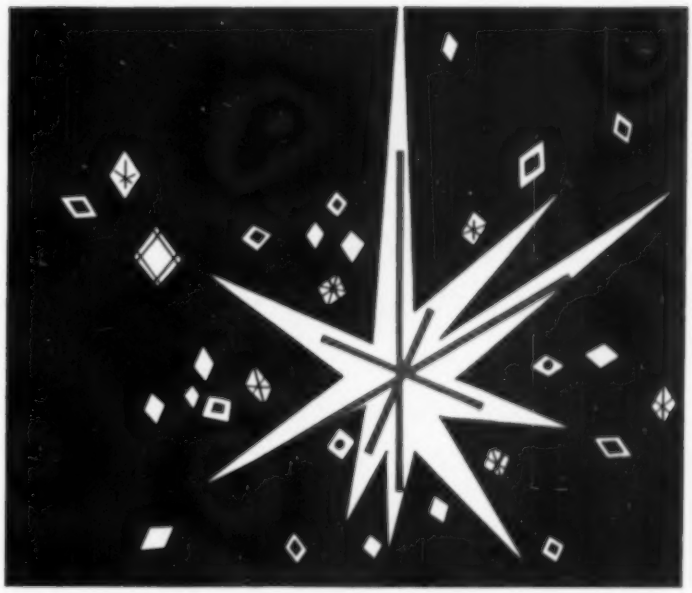
New Facilities

Heart of the $10 million expansion are two completely new reactor lines. In each line there are 11 reactors of 5,000-gallon capacity each. The new recovery area has three new stripping columns.

Included in the expansion are new spherical butadiene blend tanks (210,000 gallons each). This makes possible a sevenfold increase in storage capacity of the butadiene. Styrene storage capacity has also been increased. These new facilities should enable the plant to turn out its larger quantities with more uniform quality.

To allow more accurate control at every stage of the process, instruments and controls have been centralized.

TURN FOR MORE NEWS ON
INDUSTRY ..... page 46 et seq.
NUCLEAR ..... page 50
INSTITUTIONAL ..... page 82



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Arnold O. Beckman Gas Density Balance

...for continuous, accurate measurement of process gas streams

Arnold O. Beckman, Inc., announces their new Gas Density Balance designed and constructed for rugged industrial use. This new instrument—known as the Model 3A—gives more sensitive, more versatile and more convenient readings than *any* gas density measuring unit now in use. The Model 3A is not only suited for specific gravity measurements of process streams, but also performs equally well for quantitative measurements of natural gas, H_2, CO_2 or other gases. The Model 3A is a null-balance type instrument which measures gas density by a direct physical principle, assuring rapid and accurate readings.

HERE ARE A FEW OF ITS MANY OUTSTANDING FEATURES . . .

Ranges: Single or multiple ranges with spans from 0.05 to 5.0 sp. gr. relative to air.

Rapid Response: 95% of any reading in less than one minute.

Sensitivity and Accuracy: ± ½% of full scale.

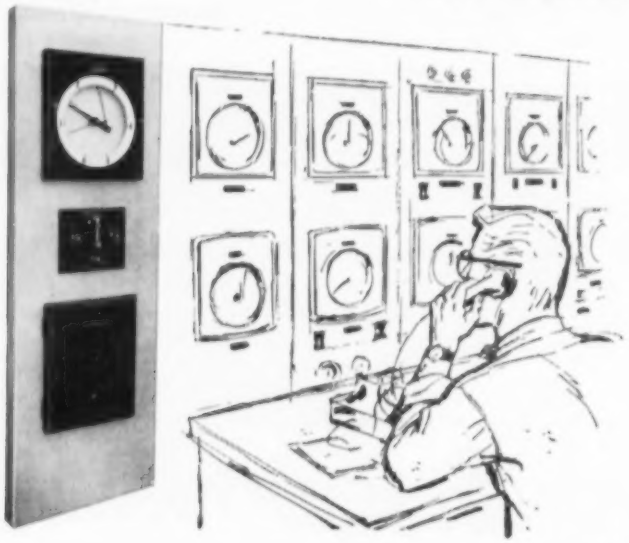
Corrosion Resistant: Measuring element protected against corrosive elements.

Output: 0-5 millivolts standard for use with potentiometer type recorders. Current or pneumatic output available with instruments having single ranges, or two or more ranges having a common end point.

Sample Required: 48 cubic inches per minute at 10 psi.

Power Required: 130 watts with 115 volts, 60 cycles.

The Arnold O. Beckman Gas Density Balance is a single compact unit, designed for wall or flush mounting. The standard steel case is vapor tight, thermally insulated and controlled so that operation is unaffected by ambient temperature changes. The unit weighs about 65 lbs. Explosion-resistant cases are also available.



For more information on the Model 3A Density Balance write directly for Data File 22A-67.

Arnold O. Beckman INC

1020 MISSION STREET • SOUTH PASADENA, CALIFORNIA

INDUSTRIAL NEWS

Said to be the first commercial oxygen manufacturing plant in Mississippi, the new facilities of National Cylinder Gas Co. in Jackson went on stream May 15, 1957. The plant, which will also produce acetylene and nitrogen, will pipe oxygen directly to the adjacent plant of the Mississippi Steel Corp. and will serve industrial users throughout central Mississippi. □

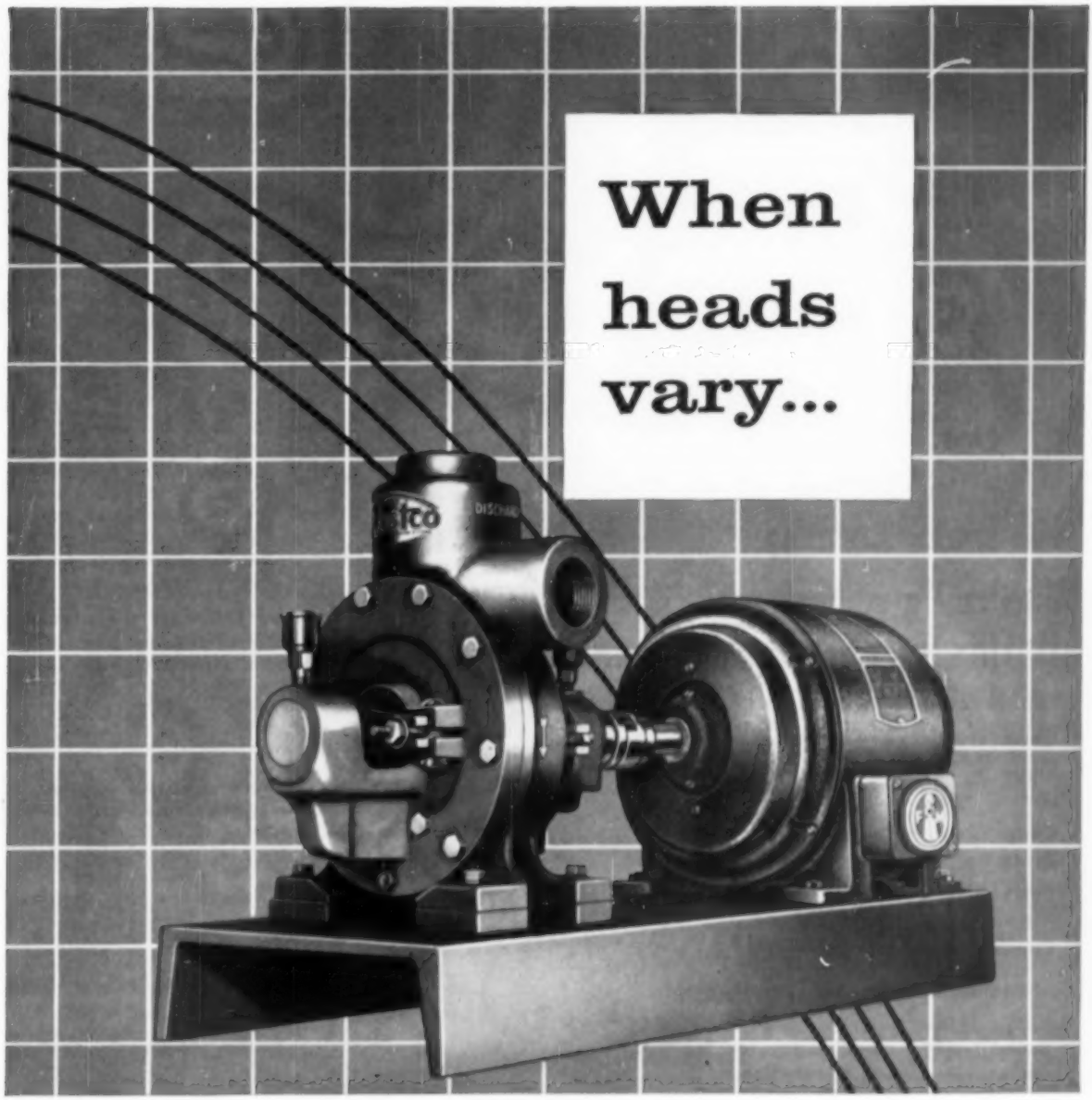
A new laboratory offering research and development services on a contract basis has been established in Madison, Wis., by Trionics Corp. Services are available to both industry and government agencies. Special fields of activity will include: high and low temperature resistant materials, coatings and surface treatments, plastics, corrosion inhibition, and radiochemistry. □

New Dow Chemical petrochemicals plant is under construction at Bay City, Mich. Petroleum by-products from the adjacent Bay Refining Corp., acquired last summer by Dow, will be piped directly to the new plant which will consist of a cracking unit, an ethylene unit, and a butadiene unit. Production, mainly ethylene, will be coordinated with Dow plastic production facilities at Midland. □

Expansion plans will more than double Plaskon melamine and urea molding compound production at Toledo plant of Barrett Division (Allied). The expansion, scheduled for completion by mid 1959, will make the Toledo facilities the largest thermosetting resins plant in the country. □

Monsanto Chemical Co. has doubled its St. Louis production capacity for bisphenol A, an intermediate used in manufacture of epoxy resins and oil-soluble phenolic resins. Increased demand for bisphenol A is attributed by Monsanto to the current epoxy boom. Domestic production of epoxies is said to have totaled 30 million pounds in 1956, an increase of more than fifty per cent over 1955. □

The entire chlorine output of Kaiser Aluminum and Chemical Corp.'s chlorine-caustic soda plant being built at Grammercy, La., will be marketed by the Industrial Chemicals Division of Olin Mathieson. Scheduled for completion this fall, the new plant will have a capacity of 100 tons a day of chlorine and equivalent caustic. The caustic will be used by Kaiser itself in its new alumina operation at Grammercy. □



Install a Fairbanks-Morse Westco peripheral pump . . . and make sure of efficiency with little or no loss of capacity!

How? Through original F-M Westco design—these pumps deliver approximately the same capacity when discharging against high pressure or low pressure—and all at 1750 rpm.! Another important point: by featuring a multi-vaned impeller, these Westco peripheral pumps deliver multi-stage performance from a single-stage pump.

You'll find Westco peripheral pumps ideal as integral parts of machines, units or systems . . . such as circulating hot water, ice water or brine . . . or for service on clear water, sump, solvents or chemical fluids, feeding filters or boilers, or as booster pumps. Capacities to 200 gpm., heads to 600 feet. For complete information and assistance contact your F-M Pump Dealer, or write today to Fairbanks, Morse & Co., Dept. CEP6, 600 South Michigan Avenue, Chicago 5, Illinois.

FAIRBANKS-MORSE

a name worth remembering when you want the BEST

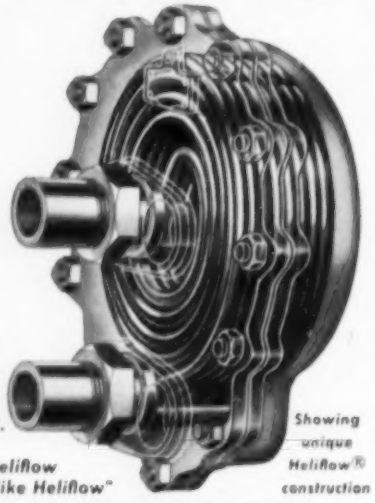
PUMPS • SCALES • DIESEL LOCOMOTIVES AND ENGINES • ELECTRICAL MACHINERY • RAIL CARS • HOME WATER SERVICE EQUIPMENT • MOWERS • MAGNETOS

Who can give you a Heat Exchanger with all this wrapped up in one package?

- Higher rates of heat transfer
- Closer temperature approach
- Elimination of temperature strains—completely
- Compactness—much smaller space requirements
- Most shipments made from stock
- Complete dependability

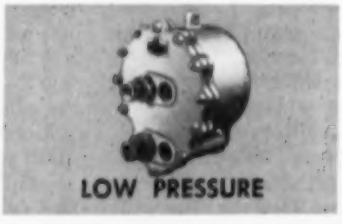
— and all at competitive prices!

So, gentlemen, the actual "low-down" is that we don't have competitors when it comes to Heliflow®.



Showing unique Heliflow® construction

Enthusiastic users of over 100,000 Heliflow units agree—"there is nothing quite like Heliflow"



With Heliflow® you CAN'T tell the difference!

Graham MANUFACTURING CO., INC.

INDUSTRIAL NEWS

American Potash & Chemical Corp. has formed a new subsidiary, San Antonio Chemicals, Inc., for which a $750,000 plant has been built at San Antonio, Texas, near the facilities of American Lithium Chemicals, Inc., another American Potash & Chemical subsidiary. The new company will process end liquors from lithium hydroxide manufacturing processes to produce a mixed alkali salt, Alkarb, composed of the metal carbonates of potassium, rubidium, cesium, sodium, and lithium. □

Hagan Chemicals & Controls, Inc., acquires Bradford Laboratories, Inc., which will function as a department of the Hall Laboratories of Hagan. The move marks an expansion of Hall industrial water service into the use of water flooding for the recovery of petroleum. □

Two new plants for the manufacture of "Styrofoam" are now in full commercial production, Dow Chemical announces. The new facilities, at Riverside, Mo., and Ironton, O., double the company's production capacity for the product. □

A $1,500,000 expansion program is under way at Vacuum Metals Corp., an operating division of Crucible Steel Co. of America's Sanderson-Halcomb Works at Syracuse, N. Y. The program will double the company's capacity for producing high-purity vacuum-melted materials. The expansion was undertaken to meet increased demand for vacuum-melted high quality bearings and high temperature alloy steels. Construction is expected to be completed before the end of this year. □

A contract to engineer and supply a fat-splitting and fatty acid hydrogenation plant for Emery Industries (Canada) Ltd., London, Ontario, has been given to Blaw-Knox' Chemical Plants Division. The new plant will use the Colgate-Emery process, a continuous method which splits the fatty acids and glycerine from either animal or vegetable fats and oils. □

Installation of new resin reactor and new materials handling equipment at Archer-Daniels-Midland Company's Pensacola, Fla., plant is expected to up the plant's production by about fifty per cent. Entire production of the Pensacola plant is scheduled to go to the protective coating industry in the South.

LUMMUS

ENGINEERS AND CONSTRUCTORS FOR INDUSTRY

385 Madison Avenue New York 17, N. Y.

PITTSBURGH COKE DOUBLES ITS PHTHALIC CAPACITY

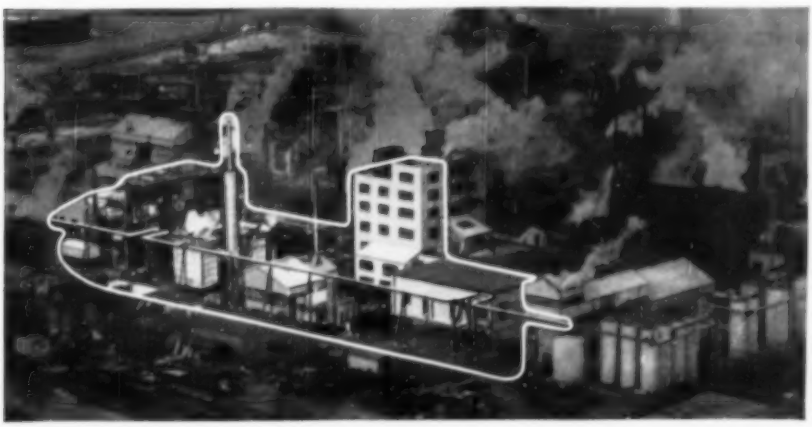
Lummus Engineers and Constructs $3 Million Plant

The recent start-up of Pittsburgh Coke & Chemical Co.'s new phthalic anhydride facilities marks another step in this company's expansion in the chemical field. Engineered and built by The Lummus Company, the new plant was integrated with existing facilities of the company's Industrial Chemicals Division on Neville Island in the Ohio River below Pittsburgh.

Since the new plant was an expansion of existing facilities, interference with current production during construction had to be kept to a minimum. This was done by close coordination between Pittsburgh Coke and Lummus engineers at all stages of the job.

The plant has a number of outstanding features. The Lummus-designed instrumentation system includes thermocouples which – at the push of a button – in the control room – travel to any desired point in the reactor as indicated on the control board. This instrumentation permits convenient checking of temperatures throughout the reactor bed. Molten salt circulated around the reactor maintains the desired temperature of reaction.

Current Lummus projects include plants for the manufacture of ethylene, ethylene oxide, pulp and paper, beryllium metal, ammonia and food products. Every Lummus project reflects the experience of many specialists in the process fields. This experience is ready to work for you – to design, engineer and build new or expanded facilities. If you have such a project in mind, discuss your plans with Lummus.



The Lummus Company, 385 Madison Avenue, New York 17, New York. *Engineering and Sales Offices and Subsidiaries:* New York, Houston, Montreal, London, Paris, The Hague, Bombay. *Sales Offices:* Chicago, Caracas. *Heat Exchanger Plant:* Honesdale, Pa. *Engineering Center:* Newark, N. J.

Outlined in white are the expanded phthalic anhydride facilities engineered and constructed by Lummus for Pittsburgh Coke & Chemical Co.

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without removing from the line!

long life—easy turning
no expensive returns
to factory for repairs

Continental-Emsco Swivel Joints save you time, money and trouble. After long service, both the packing and the ball races are easily replaceable. You can inspect and service them easily by breaking the joint as you would a pipe union. No costly return to the factory for repairs. Available in 8 basic styles and over 500 models.

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U. S. TO LEAD WORLD IN STANDARDIZING NUCLEAR ENERGY

International Organization on Standardization initiates new project for industrial nuclear energy standards, assigns leadership to the United States through the American Standards Association, its U. S. member.

In accepting ASA's assignment as the secretariat of ISO's new nuclear energy standardization project, Vice-Adm. G. F. Hussey, Jr., ASA's managing director, emphasized that "U. S. industry has recognized it cannot afford isolationism in the world race to harness atoms for peace."

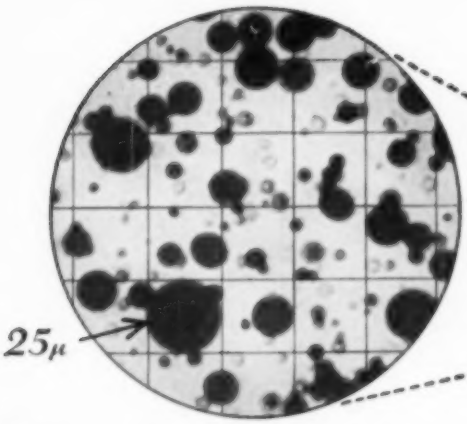
An ISO committee composed of nuclear experts from member countries will hold its organizational meeting July 29 to August 1 at Geneva. A plan for the standardization of techniques in applying nuclear power to industrial uses will be presented. Emphasis is going to be on development of safety standards.

National Standards, Too

On the national U. S. level, the Nuclear Standards Board of ASA has passed the initial planning stage, has determined what has already happened in nuclear standardization, what knowledge is available, and what organizations exist which are capable of working in this field.

Design and engineering of the Case Industrial Nuclear Center is being done by The Austin Co. of Cleveland. Preliminary designs are underway for the center which is being planned under the joint sponsorship of Case Institute of Technology and industrial firms interested in research which requires a high flux engineering test reactor. Companies involved at present, in addition to Case and the Austin Co., are: Cleveland Electric Illuminating Co.; Standard Oil of Ohio; Schenley Industries; Republic Steel; and Thompson Products, Inc. □

A major source of nuclear instrumentation information is contained in the published proceedings now available covering the Instrument Society of America's National Nuclear Instrumentation Conference. Bound copies are available from ISA at 313 Sixth Ave., Pittsburgh 22, Pa. Price: $5.00 to non members; $3.50 to members. □



Here's the *latest* on Lithium METAL DISPERSIONS

Microscope and Illuminator by American Optical Company, Instrument Division, Buffalo, New York. Polaroid® Land Camera by Polaroid Corporation, Cambridge, Massachusetts.

Got a catalyst problem?

Interest sparked by the discovery that lithium metal dispersions make unique polymerization catalysts (the polymerization of isoprene to a "natural" rubber) indicates a heretofore unexploited instrument of research.

Consequently, Lithium Corporation is now making available experimental quantities of dispersions of this highly reactive metal. These dispersions may be purchased in either mineral oil or a mineral oil-petrolatum combination as the dispersing medium. Dispersions in other media are available as special items. The "package" is obtainable in five sizes from 25 grams to 1 pound. Over 90% of the lithium metal particles have a diameter less than 25 microns.

Specifications, information for preparing the dispersions including handling instructions, prices and product data on lithium metal may be obtained by submitting a request on company or institutional stationery.

... trends ahead in industrial applications for lithium

LITHIUM CORPORATION OF AMERICA, INC.
2540 RAND TOWER, MINNEAPOLIS 2, MINN.

PROCESSORS OF LITHIUM METAL • METAL DISPERSIONS
METAL DERIVATIVES: Amide • Hydride
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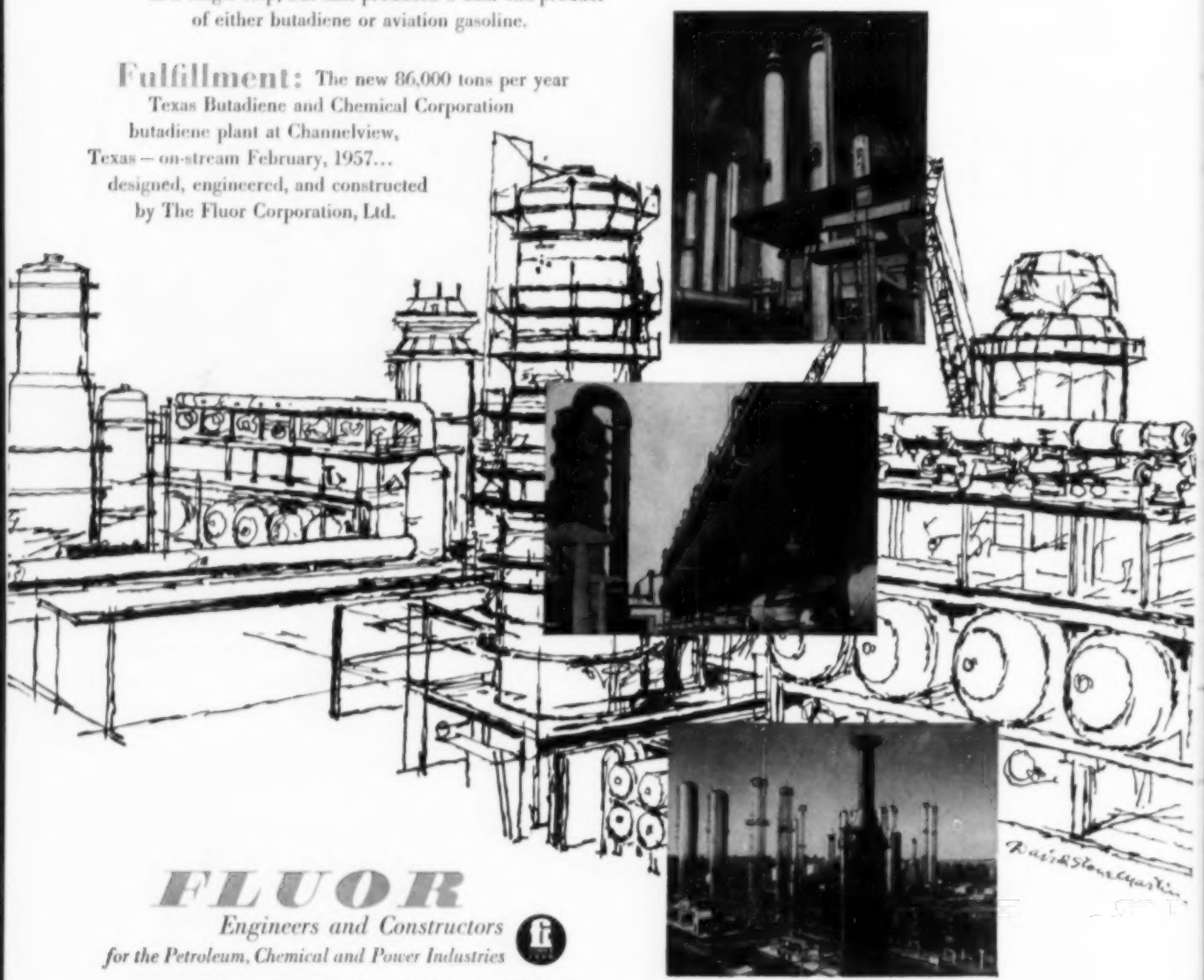
RESEARCH LABORATORY: St. Louis Park, Minnesota

Creative Challenge:

Four years ago, The Fluor Corporation, Ltd. looked into the future...anticipating the growing need for synthetic rubber.

A challenging project was assigned to the Fluor engineering staff...the design of a new type of butadiene plant that not only processed butadiene from butane in a single step, but that produced a dual end-product of either butadiene or aviation gasoline.

Fulfillment: The new 86,000 tons per year Texas Butadiene and Chemical Corporation butadiene plant at Channelview, Texas — on-stream February, 1957... designed, engineered, and constructed by The Fluor Corporation, Ltd.



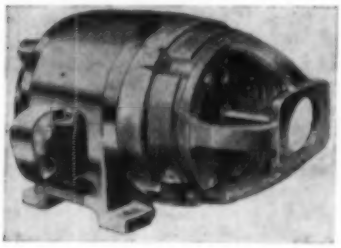
FLUOR

Engineers and Constructors for the Petroleum, Chemical and Power Industries

The Fluor Corporation, Ltd., Los Angeles — Mid-Continent Division, Houston — Research Division, Whittier, Calif. — Fluor of Canada, Ltd., Toronto — Singmaster & Breyer, Inc., New York City

CEP Data Service

DEVELOPMENTS OF THE MONTH



372 Special Hydraulic Pump Motors. New series, designed particularly for hydraulic pumps, is available in drip-proof, totally-enclosed, and explosion-proof designs. They incorporate a face-type registered bracket for mounting the pump on the motor.

Method of coupling is said to offer many advantages: separate base plates or platforms are eliminated; shorter, more compact package is achieved; built-in alignment is assured; installation time is reduced.

In drip-proof design, Type H motors are available to 20 hp and Type SC to 125 hp. Totally-enclosed and explosion-proof designs are available in Types J and E to 10 hp, and in Types SD and SE to 125 hp. For double end pump installations where low pressure-high volume and high pressure-low volume pumping is required, these pump motors can be supplied with double end shafts and mounting brackets for supporting two pumps.

Data sheets available from U. S. Electrical Motors, Inc. Circle number 372 on Data Post Card.

ENGINEERING DATA—MATERIALS

301 Calcium Silicate Insulation. 6-page bulletin gives basic data on "Thermasil" insulation for pipe covering, process vessels, etc. Ehret Magnesia Manufacturing Co.

302 Properties of Zirconium & Zircaloys. Special Analysis Memorandum from Superior Tube Co. gives physical and mechanical properties.

303 Pamphlet on Tall Oil. Average characteristics, specifications, and application information. Welch, Holme & Clark Co., Inc.

304 Stearic Acid Selection Data. 24-page booklet from Emery Industries gives composition of typical grades and selection chart.

305 Properties of Commercial Glasses. Thermal, electrical, chemical properties. Viscosity temperature curves, heat transmission data. Bulletin from Corning Glass Works.

306 Adhesives, Protective Coatings, Sealers. Recommend use, method of application, properties of eight "Ray-Bond" adhesives. Folder from Raybestos-Manhattan, Inc.

307 Stainless Steel Data Sheet. Physical, mechanical properties, corrosion and oxidation resistance of special Type 418 stainless. Allegheny Ludlum Steel Corp.

308 Sulfur Brochure. Comprehensive 48-page brochure from Stauffer Chemical gives statistics, specifications, physical and chemical properties of various forms of sulfur.

309 Acid-Resistant Lubricant. Special "Keystone 2K-6" lubricant said to resist oxidation and to be acid-free. Complete information from Keystone Lubricating Co.

310 Comprehensive Filter Paper Catalog. 24-page catalog, many photos, charts, and diagrams. Eaton-Dikeman Co.

311 Gauge and Sight Glasses. Bulletin from Swift Lubricator Co. gives working pressures, dimensional tolerances, weights of wide range of glasses.

312 Liquid Plastics Chart Guide. Liquid vinyls, epoxies, liquid neoprenes, specialized coatings. Protective Coatings, Inc.

314 Adsorbents. Comprehensive catalog from Floridin Co. gives data on Florida Fullers earth, domestic activated bauxite, and "Florisil" synthetic magnesium silicate.

315 Titanium Pipe and Tubing. Technical data folder from Tubular Products Division, Babcock & Wilcox Co., gives mechanical, physical, and working properties of titanium in tubular form.

316 Silicones Catalog. Illustrated brochure describes more than 115 different applications for silicones. Silicone Products Department, General Electric Co.

317 Dermatitis Control Booklet. 24-page booklet from West Disinfecting Co. describes causes of industrial dermatitis and methods of treatment.

(Continued on page 58)

DEVELOPMENTS OF THE MONTH (Cont.)

373 Controlled-volume Pump Bulletin. Thirty-two page brochure from the Milton Roy Co. gives exhaustive details on their line of motor-driven controlled-volume pumps.

Pumps are the reciprocating positive displacement type and are designed to meter liquids accurately within plus or minus one per cent against a positive pressure differential between suction and discharge.

Capacities range from about 45 gal./min. down to as little as 3 milliliters/hr. Pressures may range from a few pounds per square inch up to 50,000 lb./sq.in.

For information, circle number 373 on Data Post Card.

CEP Data Service

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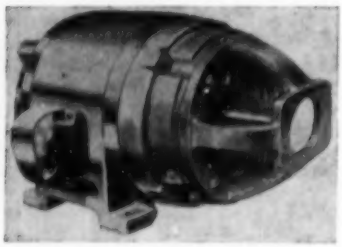

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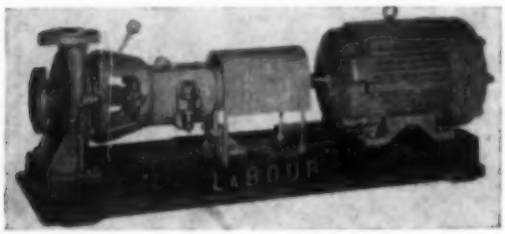
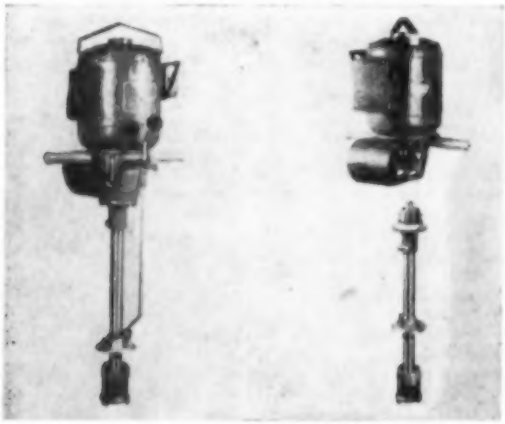


374 Non-priming Centrifugal Pump. New type pump which makes possible easy maintenance by removal of the working parts as a unit separable from the piping system is offered by the LaBour Co., Inc. All rotating parts of the Type SZ pump are contained in a single assembly which may be removed or replaced as a unit without disturbing pipe connections or motor and without affecting alignment.

To permit the drive unit to be pulled away from the casing, a flexible coupling spacer is removed. This permits the drive unit to be disconnected and removed as an assembly for replacement or repair.

Fully-open impeller uses no sealing rings or closely-fitted running parts. The impeller shaft may be mounted separately to the drive shaft or may be welded to form a one-piece construction with the drive shaft. Circle number 374 on Data Post Card.

DEVELOPMENTS OF THE MONTH (*Cont.*)



375 Interchangeable-head Mixers. In the Shear-Flow industrial mixer, the complete mixing head is a compact self-contained unit consisting of the mixing shafts, stator-housing, counter-rotating impellers, seals, and all related parts. Removal of four retaining bolts and loosening of the drive belt disengages the mixing head, permitting the insertion of a new head as soon as the other is removed. Spare mixing heads are available for all production models in 3 impeller sizes. All parts subject to immersion are constructed of corrosive-resistant materials. Manufactured by Gabb Special Products, Inc. Circle number 375 on Data Service Post Card.

(Continued on page 55)

Numbers followed by letters are for checking your interest in the products, equipment, and services advertised in this issue, the number corresponding to the page on which the ad appears. Letters indicate position on the page: L, Left; R, right; T, top; B, bottom. A indicates a full page; IFC, IBC, and OBC are cover advertisements. **Numbers in the 300-series** bring you new engineering data in the chemical engineering field.

Be sure to include your name, address, and position.

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43A 45A 46L 47A 48L 49A 50L 51A 52A 57A 59A
61A 63A 64L 65A 66-67A 68A 70L 71A 72L 73A 74L
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IFC 3R 4A 7A 8-9A 10L 11A 12A 13A 15A 16A
17A 18A 23-24A 25A 26L 27A 28TL 28BL 29A 30L
31A 32L 33A 34L 35A 36A 38A 260A 39A 41A
43A 45A 46L 47A 48L 49A 50L 51A 52A 57A 59A
61A 63A 64L 65A 66-67A 68A 70L 71A 72L 73A 74L
75A 77A 78L 79A 80L 81A 82L 83A 84L 85A 86L
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DEVELOPMENTS OF THE MONTH (*Cont.*)

376 Vertically-split Centrifugal Pump. Worthington Corp. offers a new vertically-split centrifugal pump especially designed for heavy-duty service in the chemical, petroleum, and allied industries.

Constructed with centerline-supported casings and circular casing joints with confined gaskets, the new HN pump is said to be suitable for temperatures up to 850° F.

Casing thicknesses have been designed to withstand safely working pressures up to 600 lb./sq.in. gauge with an economical 1/8-in. minimum corrosion allowance. Shafts and bearings are sized for minimum deflection to provide trouble-free service under difficult suction conditions up to 500 lb./sq.in. gauge.

Pumps are available in three models: Type HN-end suction, top discharge; Type HNT-top suction, top discharge; and Type HNC-integral seal.

Standardized parts provide maximum interchangeability. Special alloys can be provided. Technical bulletin from manufacturer. Circle number 376 on Data Post Card.

A.I.Ch.E. MEMBERSHIP

Brochure—"Know Your Institute"—tells objective aim and benefits to chemical engineers who join this nation-wide organization, includes membership blank. Circle number 377 on Data Post Card.

378 Low-Cost Heat Exchangers. New line of "Hi-Transfer" exchangers is now available from Whitlock Manufacturing Co. in a wide range of standard sizes.

Units are designed to assure maximum heat transfer with minimum pressure drop. Shell and tubes are made for working pressures of 75 lb. and are tested at 115 lb. All parts and exchanger units are completely interchangeable to permit fast, easy installation and servicing.

Bronze bonnets and tube sheets, seamless copper shells, Admiralty tubes, and brass baffles provide maximum corrosion resistance. Zinc anodes are also available when required for specific applications.

Parts are readily accessible to facilitate maintenance. The tube bundle can be inspected by removing the bonnets and the tubes can be cleaned easily because of the straight tube design. For descriptive bulletin, Circle number 378 on Data Post Card.

(Continued on page 58)

PRODUCTS ADVERTISED IN THIS ISSUE

IFC Fractionation, Absorption, and Extraction Towers. Bulletin titled "Distillation Engineering and Equipment" offered by Vulcan-Cincinnati, Inc.

3R Bulk Feeders. Drayer Feeders, product of B. F. Gump Co. now available with automatic timing controls. Consulting services on request.

4A Mist Eliminators, Entrainment Separators. Otto H. York, engineers and manufacturers, are specialists in fluids separation. Literature.

7A Controlled-Volume Chemical Pump. Bulletin from Lapp Insulator Co., Process Equipment Division, gives applications, flow charts, specifications.

8A-9A Air and Gas Compressors. Complete line of reciprocating and centrifugal compressors for the process industries. Pressures to 35,000 lb./sq.in., capacities to 255,000 cu.ft./min. Ingersoll-Rand.

10L Cementable Teflon. Provides frictionless linings for dry chemical handling problems. Bulletin from United States Gasket Co.

11A Pilot Plant Heat Transfer Units. Pressures to 500 lb./sq.in. Temperatures to 750° F. Sizes from 0.7 to 60.0 sq.ft. heat transfer surface area. Bulletin from the Girdler Co.

12A Vacuum and Pressure Filters. Detailed technical information and consulting services available from the Eimco Corp.

13A Fluid Mixer Assembly Catalog. Comprehensive mechanical design information permitting selection of complete paddle and turbine type fluid mixers. Philadelphia Gear Works, Inc.

15A Rotary Blender Bulletin. Nine standard models with capacities from 10 to 900 cu.ft. Bulletin from Sturtevant Mill Co. gives complete specifications.

16A Pump Catalog. Technical catalog from Aldrich Pump Co. describes complete line of pumps for the chemical process industry.

17A Drying Test Service. Exhaustive tests, complete and accurate product analysis, objective and unbiased conclusions. Wyssmont Co.

18A Pressure Control Pilots. Bulletin from Leslie Co. gives complete technical data and typical applications sketches.

23A-24A Product Information. Bulletins from U. S. Industrial Chemicals Co. on polyethylene tubes, plastic pumps, zirconium alloys, other recent technical developments.

25A Impervious Graphite Products. Selection guide for "Karbate" impervious graphite and "National" resin base cements available from National Carbon Co. Also catalog on graphite heat exchangers.

26L Pulse Code Telemetering Systems. Bulletin—"A Comparison of Current Telemetering Systems." Vapor Recovery Systems Co.

27A Compact Process. Converts waste into profit. Complete story from Allis-Chalmers, Industrial Equipment Division.

28TL Scale Feeders. For continuous dry blending. Feed rates from 3 ounces to 3,000 pounds per minute. Accuracy within 1% of feed rate. Wallace & Tiernan, Inc. Booklet on Merchen feeders.

28BL Chlorinators and Chemical Feeders. For slime elimination, water treatment and purification, industrial waste and sewage treatment. Wallace & Tiernan, Inc.

29A Vinyl Resin Plants. Blaw-Knox Co. is a pioneer in the design, engineering, and construction of complete plants for the resins and plastics industry. Consulting services offered.

30L Automatic Weighing Equipment. Flooding powders accurately batched with Thayer Scale "Autoweightion" System. Engineering data from Thayer Scale Co.

31A High Temperature Heat Transfer Systems. "Beth-Tec" system uses molten salt mixture (DuPont's Hi-Tec) which melts at 280° F. Folder with complete details from Bethlehem Foundry & Machine Co.

32L Tray Dryers. Single or multiple stacked for highly varied drying speeds and material loads. Technical details from C. G. Sargent's Sons Corp.

33A Design and Construction Services. Petroleum refining, chemical plants, ore beneficiating mills. Also process equipment. Brochure from Southwestern Engineering Co.

34L Rubber-Lined Equipment. Eleven basic materials. Wide range of temperatures, pressures, strengths. Details from American Hard Rubber Co.

35A Leak-Proof Pumps. No seals, no stuffing box, no packing. No external lubrication. Pump and motor in single, leak-proof unit. Chempump Corp.

36A Corrosion-Resistant Heat Exchangers. In stainless, nickel, nickel alloy, aluminum, bronze, carbon, and many other materials. Downingtown Iron Works, Inc. Bulletin.

38A Stainless Steels. Booklet—"Making the Most of Stainless Steels in the Chemical Process Industries," forty-four pages. Crucible Steel Co. of America.

260A Painting Manual. Detailed data on characteristics of Tygon protective coatings. U. S. Stoneware.

39A Mixer Bulletins. Detailed information and useful design data from Turbo-Mixer Division, General American Transportation Corp.

41A Vinyl Resins. Complete line of vinyls engineered to the specific need of the chemical industry. Information and technical service available from Chemical Sales Division, Firestone Plastics Co.

42A "Isoflow" Furnaces. Unlimited in size, capacity, and duty. Technical data from Petro-Chem Development Co.

45A Crystallization Equipment. Controlled, uniform crystal size, high purity, lower production cost. Bulletin from Struthers Wells Corp.

46L Gas Density Balance. For continuous, accurate measurement of process gas streams. Data file from Arnold O. Beckman, Inc.

47A Peripheral Pumps. Deliver approximately same capacity when discharging against high or low pressure at same speed. Capacities to 200 gal./min. Heads to 600 feet. Fairbanks, Morse & Co.

48L Heat Exchangers. Higher rates of heat exchange, closer temperature approach. Graham Manufacturing Co.

49A Plant Design and Construction. New phthalic anhydride facilities of Pittsburgh Coke & Chemical engineered and constructed by the Lummus Co.

50L Swivel Joints. Break like a union, packing easily replaced. Eight basic styles, over 500 models. Technical information from the Continental-Emsco Co.

51A Lithium Metal Dispersions. Experimental quantities now available from Lithium Corp. of America.

> ○ **CIRCLE** *your Data Service requests on the handy postcard on page 54 to*
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52A Butadiene Plants. New 86,000 tons per year Texas Butadiene and Chemical Corp. plant designed, engineered, and constructed by the Fluor Corp.

57A Heat Exchangers. Patterson Kelley, Chemical and Process Division, invites inquiry on design and fabrication of heat exchangers.

59A Inert Gas Generator. Packaged unit assures constant analysis gas whether at 20 or 100 per cent of capacity. Capacities from 250 to 150,000 cu.ft./hr. Gas Atmospheres, Inc.

61A Pressure Centrifuge. Merco pressure centrifuge offers pressure operation, no solids build-up, no nozzle clogging, practical design. Bulletin from Dorr-Oliver.

63A Drying Services. Expert services in the testing and specification of all types of drying equipment available at Proctor & Schwartz, Inc.

64L Spray Nozzle Catalog. Details on nozzle applications, sizes, capacities, spray pat-

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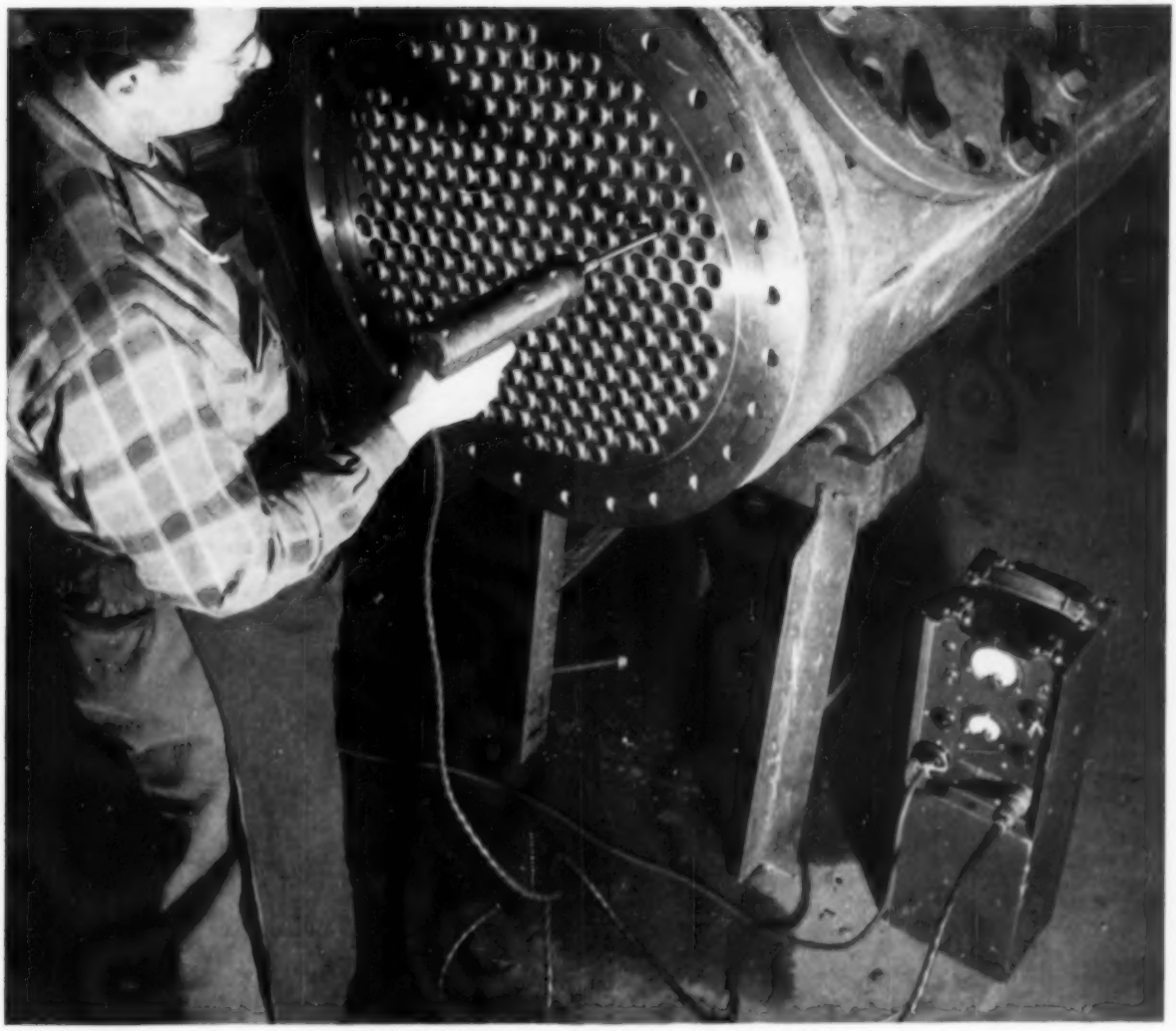

LEAK DETECTION . . . another reason why you get more for your dollar with p-k heat exchangers

The man above is "snooping" around a P-K heat exchanger to make sure it is leak free. The instrument he's using is an extremely sensitive leak detector which picks up even the slightest trace of a gas or vapor leak. For example, it can detect a leak so small that it would take a year for 1/100 of an ounce of gas or vapor to escape without discovery.

This leak detection test is only one of the many fabricating and testing procedures that make P-K heat transfer equipment the best you can have. For another example, every weld is x-rayed so that any flaw can be eliminated; each tube end is expanded electronically for the most perfect fit. Each unit's thermal rating is scientifically checked to assure that it will perform exactly at its rated capacity.

Precautions like these are the reasons why more and more processors, engineers and contractors are turning to P-K for their exchanger needs. P-K invites your inquiries about the design and fabricating of heat exchangers. Write, phone or visit The Patterson-Kelley Co., Inc., 106 Burson Street, East Stroudsburg, Pa.

Patterson Kelley

Chemical and Process Division

Heat Exchangers • Converters • Storage Water Heaters • Condensers
Storage Chillers • Oil Heaters • and all types of heat transfer equipment

MATERIALS (Cont.)

318 Primary Amyl Alcohohl. 4-page technical bulletin from Union Carbide Chemicals Co. gives physical properties, specifications, shipping data, uses, and physiological properties.

DEVELOPMENTS OF THE MONTH (Cont.)

379 Miniature Hydraulic Valve Actuator. System of miniature hydraulic actuation, developed by Oil-Dyne, Inc., is said to offer many advantages over old-style hydraulic actuation or pneumatic actuation, especially on larger size valves and on application where higher pressures are involved.

Oil-Dyne units are available in a full

range of types and motor sizes. Explosion-proof housings are available for all standard units.

Special design engineering service for specific applications is available from the manufacturer. Complete technical information including new fifty-two-page catalog will be sent on request. Circle number 379 on Data Post Card.

(Continued on page 60)

319 New Structural Material. "Lamicor," product of the Strick Plastics Corp., said to offer unprecedented combination of chemical, electrical, mechanical, and structural properties. Bulletin and data sheets.

320 Aluminum Pipe Brochure. Describes use for tank and vessel hook-up. Handy reference tables scheduling available sizes and specifications. Reynolds Metals Co.

321 Phenolic Impregnations. Data sheets from U. S. Polymeric Chemicals, Inc., describe selection of products ranging from melamine-impregnated paper through complete line of glass fibers and mats in combination with such thermo-setting resins as epoxy, polyester, phenolic, silicone, diallyl phthalate, melamine.

322 Acrolein Dimer Bulletin. Physical properties, shipping data, chemical properties, reactions, and physiological properties. Union Carbide Chemicals Co.

323 Protective Lining Brochure. 4-page booklet describes sheet linings, sprayed metal coatings, synthetic resin coatings, combination coatings, sand and grit blasting. Metalweld Inc., Protective Coatings Division.

324 Alloy Pipe and Tubing Catalog. Trent Tube Co., subsidiary of Crucible Steel Co. of America, offer forty-eight page catalog describing products from ⅛ to 40 in. diam. in stainless and high alloy steels.

325 Radioactive Isotopes. Technical bulletin from Nucleonic Corp. of America describes complete line of radioactive isotopes for industrial, medical, research, and educational use.

326 Industrial Chemicals. Bulletin from Tennessee Corp. describes wide range of industrial and agricultural chemicals.

SERVICES

327 Diammonium Phosphate Plant Design. John J. Harte Co. offers proven processes, design and construction services for plants to produce diammonium phosphate and wide range of other fertilizers and industrial chemicals.

328 Consulting Engineering Services. Foster D. Snell offer 26-page brochure "How to Develop Successful New Products." Principles of operation and case histories are discussed.

EQUIPMENT

329 Polyethylene Ventilators. Designed to handle static pressures from ⅛ to 4 in., and to move from 100 to 3,400 cu.ft. per minute of air. Details from American Agile Corp.

330 Oil Filters. Specifications, application data, flow rate, pressure and viscosity data on series "R" filters, product of the Hilliard Corp. Features are throw-away cartridge and easy servicing.

331 Saran-Lined Centrifugal Pumps. In 1½ inch × 1-inch and 3-inch × 2-inch sizes, completely lined with Saran and equipped with mechanical rotary type seals. Construction details, operating characteristics from Dow Chemical Co.

332 Condenser Tube Handbook. 162 pages of information on corrosion and how to combat it. Bridgeport Brass Co.

333 Plastic Steam Jet Ejectors. Wide range of plastic formulations to resist hydrochloric acid, chlorinated solvents, hydrofluoric acid, many alkalies, chlorine gas, many organics. Haveg Industries. Literature.

334 Heat Exchangers. Stock sizes, dimensions, weights, of complete line of non-ferrous heat exchangers in bulletin from Whitlock Manufacturing Co.

335 Selection Manual for Corrosion-Resistant Pumps. Comparative data for four types of pumps for any application up to 350 gal./min. Capacity charts and complete specifications. American Hard Rubber Co.

336 Pinch Type Valves. 48-page catalog from Farris Flexible Valve Corp. details full line of flexible, pinch-type, hose-bodied valves in both "Standard" and new "Super-Seal" metal-enclosed designs.

337 Spray Nozzle Data Sheet. Hollowjet spray nozzles, product of Spraying Systems Co., available in capacities from 1.5 to 1,100 gal./min. In pipe connection sizes from ¼ to 5 inch, in brass, steel and stainless.

338 Fluo-Chlorinator Catalog. Safety, non-pulsating application, simplicity, corrosion-resistance. Manual, semi-automatic, automatic, multiple rate control methods. Fischer & Porter Co.

339 Corrosion-Resistant Fittings. 21-page catalog from Horace T. Potts Co. gives technical details of line of "Speedline" stainless steel fittings.

340 Pump Catalog. Capacity, performance charts, engineering specifications on complete line of positive displacement sanitary and corrosion-resistant pumps. 64 pages. Waukesha Foundry Co.

341 Vibrating Screen Separator Catalog. Operating and application data for wide range of process industries. Southwestern Engineering Co.

342 Evaporators. High speed recirculating and falling tube evaporators in multiple effect. Bulletin from Goslin-Birmingham Manufacturing Co.

343 Liquid Meter Selection Data. 28-page bulletin with charts giving construction details, register types, sizes. Neptune Meter Co.

(Continued on page 60)

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HERE's the packaged inert generator industry has been waiting for. It comes complete, ready to hook "on line" and go to work. The desirable single burner design eliminates control problems, assures constant analysis gas whether operating at 20% or 100% of capacity. Any gaseous fuel or light fuel oil can be safely used, including pure hydrogen for the production of nitrogen. Combustion chamber and heat exchanger are of stainless steel—designed to reduce surface temperatures well below safety margin.

Electrical circuits permit automatic purge and safe start in accordance with Factory Mutual and Insurance Underwriters codes.

But we've only scratched the surface—be sure you get all the facts on the advanced Gas Atmospheres packaged units before you buy.

Inert gas units available from 250 CFH to 150,000 CFH.

End view shows modern control and simplicity of single burner construction.

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344 Centrifugal Collectors. Complete specifications for 41 sizes of centrifugal collectors made by Kirk & Blum Manufacturing Co. Dimensional drawings, selection data.

345 Weather-Protected Motor Bulletin. For continuous outdoor operation in wind, rain, sand, sleet or snow. Ratings from 250 to 900 hp. Allis-Chalmers.

346 High Vacuum Equipment. 16-page price list and product index covers 400 items including diffusion pumps, rotary gas ballast pumps, mechanical booster pumps, vacuum gauges, seals and valves. NRC Equipment Corp.

347 Portable Ribbon Mixers. In carbon steel, stainless or Monel, with or without heating or cooling jackets. From 0.34 to 20 cu.ft. working capacity. Details from Young Machinery Co.

348 Standardized Heat Exchangers. Pfaudler Co. offers complete line of single and double-pass carbon shell heat exchangers for two-week delivery.

349 Quick Connect Couplings. With Teflon or Kel-F seals, for handling acids, alkali, solvents, from minus 100 to plus 500° F. For live steam up to 460° F. Bulletin from Snap-Tite, Inc.

350 Impervious Graphite Rupture Disks. Accurate to plus or minus 5% of rated burst. 100% clean rupture. Unaffected by practically all corrosives at temperatures to 650° F. Bulletin from Falls Industries, Inc.

351 Corrosion-Proof Expansion Joints. Bulletin from Garlock Packing Co. describes seven styles of rubber, neoprene, and Teflon-lined expansion joints and flexible couplings.

352 Continuous Solid-Liquid Contactor. Designed for large scale extracting operations in chemical processing industries, new unit made by Gifford-Wood Co. features unique slow motion agitation action. Literature.

353 Fluid Control Valves. For air, oil or water hydraulic use. Designed for pressures from 200 to 5,000 lb./sq.in. Available in sizes from ⅛ through ¾ in. Catalog from Modrich Fluid Controls, Inc.

354 Diesel-Engine Compressors. Booklet from Ingersoll-Rand describes new line of "SVO" integrally-built, diesel-engine compressors which combine a 4-cycle V-angle heavy duty diesel engine with a slow speed horizontal compressor on a single crankshaft, without the use of gears or other coupling mechanism.

355 Thermal Precipitators. For accurate sampling of small particulate matter in air or other gases. Bulletin from Joseph B. Ficklen, 3rd, describes continuous, gravimetric and oscillating types.

356 Tanks and Equipment for Fertilizer Plants. R. D. Cole Manufacturing Co. are designers, fabricators, and erectors of tanks and equipment in steel, stainless, aluminum, and alloy plate. Bulletin.

357 Pneumatic Control System. Complete information on Speedomax G pneumatic control available in 12-page folder from Leeds & Northrup Co. Photographs, line drawings, and block diagram of system.

358 Non-Lubricated Bearings. Catalog from Electro-Nite Carbon Co. describes non-lubricated bearings made from carbon graphite material. Nomograph charts, grades, and design information.

359 High-Pressure Control Valves. Especially designed for automated control. Suitable for oil, air, steam, and hot or cold water up to 6,000 lb./sq.in. Diaphragm-operated. Technical details from Sinclair-Collins Valve Co.

360 Spray Dryers for Ceramic Industry. Employ abrasion-resistant atomizing unit to insure quality product at low operating cost. Bulletin from Bowen Engineering, Inc.

361 Temperature Monitoring Systems. Thermo Electric Co. offers new bulletin describing various standard sub-assemblies and their arrangement to form one completely integrated temperature monitoring system for capacities up to several hundred points.

362 Molten Metal Immersion Thermocouple. New thermocouple for high temperature molten metal measurements up to 3,100° F. is offered by the Bristol Co. Technical information available from the maker.

363 Small Corrosion-Resistant Pump. No contact of moving parts with the fluid being pumped. Effective for wide range of corrosive, sterile, and abrasive materials. Details from the Randolph Co.

364 Hydraulic Power Unit Catalog. Complete technical data and specifications on 2,240 types and models of Oil-Dyne pumps, single and duplex pressure switches, hydraulic cylinders and accessories. Oil-Dyne Inc.

365 Rubber-Lined Tanks. Bulletin describes line of rubber-lined tanks for storing wide variety of chemical solutions. Gates Rubber Co. Sales Division, Inc.

366 Research and Pilot Plant Equipment. Bulletin from C. O. Bartlett & Snow Co. describes six different models of laboratory size dryers, calciners and kilns for use in research, experimental, pilot plant, and product development work.

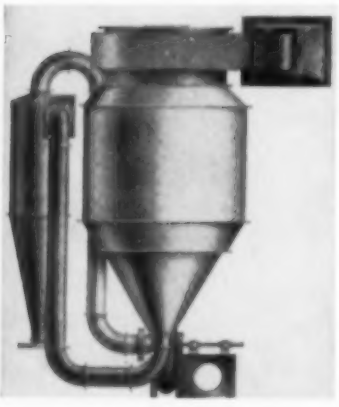
367 Filter Press Bulletin. Gives sizes and capacities of wood and metal filter presses available from the Independent Filter Press Co., Inc.

368 Grinding and Pulverizing Equipment. New bulletin from American Pulverizer Co. gives technical details of hammermills, shredders, rolling ring crushers, and special purpose crushers.

369 Laboratory Instruments. 36-page catalog from E. H. Sargent & Co. lists complete line of laboratory instruments for scientific and industrial use.

370 Automatic Control Systems. 4-page bulletin discusses application of new "Electrionic" temperature controls for the heating, ventilating, and air conditioning field. Barber-Colman Co.

371 Batch Pressure Filters. Dorr-Oliver offers bulletin describing design, materials of construction, and operation of the "Sweetland Pressure Filter." Typical installation flowsheet and specification chart.



DEVELOPMENTS OF THE MONTH (*Cont.*)

380 Pilot Plant Spray Dryer. A basic unit which can be used for drying problems of a general nature and which can be converted quickly to meet almost all pilot plant needs is available from Proctor & Schwartz, Inc.

The basic unit is suitable for drying problems of a general nature and when a wide variety of products are to be processed. Addition of Accessory Group A converts the machine for the drying of high viscosity materials which require a longer falling rate period during drying.

Addition of Accessory Groups A and B converts the basic dryer for the production of hollow spheres or thin walled "beads." Groups A and C are used for conversion to a "dispersion" type dryer for the rapid processing of wet granular materials from filter press operations and the like.

Units are furnished complete with structural supports and standard electric motors. Normally, steam or gas heating is supplied; electric heating is available at a slight increase in price.

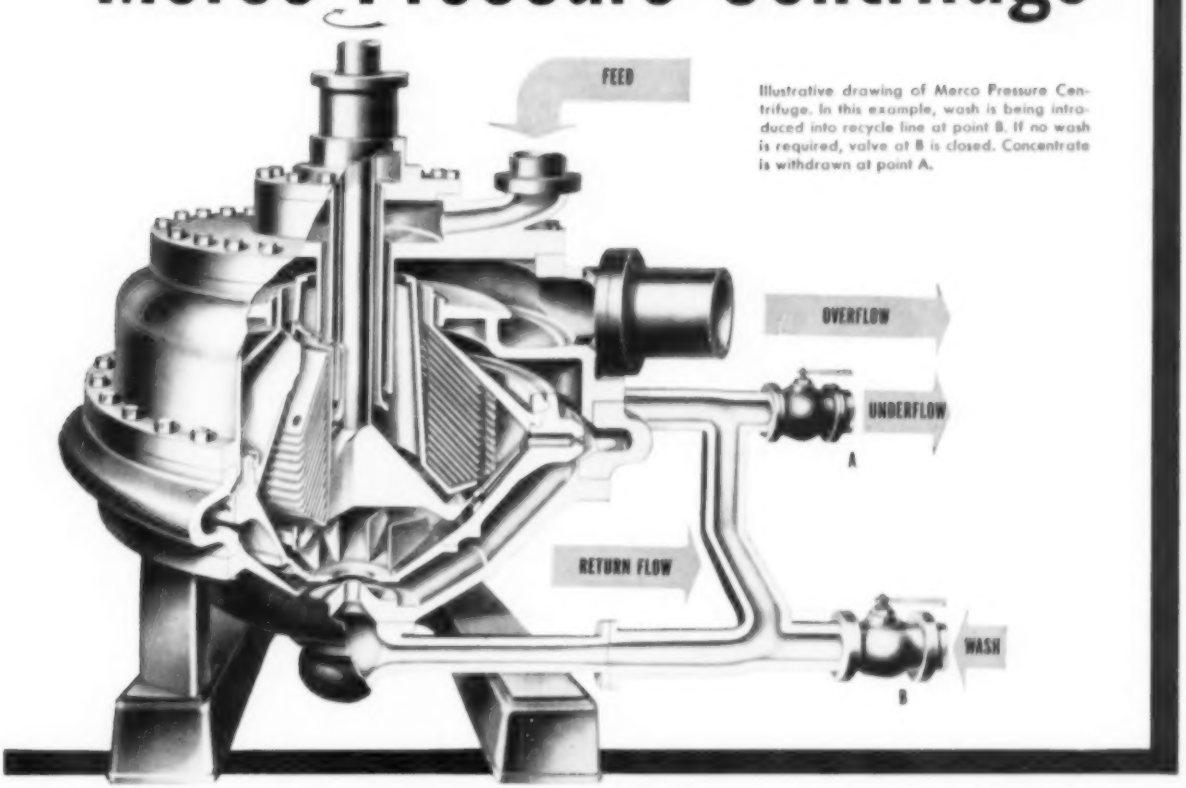
Complete technical information is available from the manufacturer. Circle number 380 on Data Post Card.

(Continued on page 62)

NOW

Centrifugal Separations under pressure conditions with the new

Merco Pressure Centrifuge



Illustrative drawing of Merco Pressure Centrifuge. In this example, wash is being introduced into recycle line at point B. If no wash is required, valve at B is closed. Concentrate is withdrawn at point A.

Newest development in wet processing equipment, the Merco Pressure Centrifuge is designed for all continuous centrifuging applications at pressures up to 110 psi. Key to pressure operation is a specially designed housing closure that has been exhaustively tested at pressures two to three times the guaranteed figure of 110 psi. Equally important, this new unit incorporates the unique Merco "Return Flow" principle for maximum operating flexibility. Under centrifugal forces thousands of times higher than gravity, even the smallest particles in the feed "sink" rapidly outward and are continuously expelled through fixed open nozzles in the rotor. A controlled portion is withdrawn as finished concentrate and the remainder becomes a return flow to the rotor. Wash, if desired, is introduced to the return flow line . . . clear, excess liquor overflows out the top of the unit.

If there's a step in your flowsheet involving concentration, washing, clarification, soluble recovery, or classification *under pressure*, there is a good chance that this new tool will prove useful. Bulletin No. 2600, just off the press, describes the Merco Pressure Centrifuge in detail. For your copy, write Dorr-Oliver Incorporated, Stamford, Conn.

Check these positive advantages . . .

Pressure Operation — Concentration, washing, clarification, soluble recovery or classification can be carried out under pressure.

No Solids Build-up — All solids entering the unit are continuously discharged. Return flow flushes solid material at periphery of rotor.

No Nozzle Clogging — Return flow principle permits nozzle flow 2 to 10 times as great as the underflow actually withdrawn. Merco nozzles will discharge particles as large as 1/32 inch.

Practical Design — All separating conditions are controlled externally. The unit is equipped with a sturdy housing which has been X-rayed and hydrostatically tested.

Merco T.M. Reg. U. S. Pat. Off.

DORR-OLIVER
INCORPORATED
WORLD-WIDE RESEARCH • ENGINEERING • EQUIPMENT
STAMFORD • CONNECTICUT • U.S.A.

PRODUCTS ADVERTISED IN THIS ISSUE (Cont.)

terns, and metals. Simple selection tables. Binks Manufacturing Co.

65A Propulsion Systems and Equipment. Research, analysis, design, prototype fabrication and test, and manufacture. Propulsion Research Corp., subsidiary of Curtiss-Wright Corp.

66A-67A Process Control System. Floating disc system in M/58 Controller, product of the Foxboro Co., insures versatility, precision, and stability. Bulletin.

68A Heat Exchangers. M. W. Kellogg Co. is equipped to handle complete job of designing, engineering, and fabricating. Any size, any design.

70L Vibratory Feeders. Complete catalog from Syntron Co. gives details of "Vibra-Flow" vibratory feeders.

71A Petrochemical Plants. England's largest refinery will be designed and built by Foster Wheeler Corp. for Esso Petroleum Company Limited.

72L Industrial Wire Cloth. Nine weaves in any metal or alloy. Eighty-page catalog and price list from Cambridge Wire Cloth Co.

73A Anodes. Consulting services and outstanding products available at Great Lakes Carbon Corp., Electrode Division.

74L Filtration Catalog. Specifications and technical data on filter presses manufactured by D. R. Sperry & Co.

75A Centrifuges. "Super-D-Hydrator," produced by the Sharples Corp., shows excellent results in the recovery of sodium chlorate crystals.

77A Liquid Level Controls. Bulletin from Fisher Governor Co. describes "Series 2800" controls. Float actuated and available with either electric or pneumatic switch action.

78L Mist Eliminators. Bulletin from Metal Textile Corp. describes technical advantages of Metex "Hi-Thruput" mist eliminators.

79A Chemical Processing Equipment. For deaeration, deodorization, esterification, concentration, stripping, distillation, evaporation, etc. Technical data from Rodney Hunt Machine Co.

80L Viscosity Measurement and Control. More than 300 technical articles and references available from Brookfield Engineering Laboratories, Inc.

81A Super Refractories. Bulletin from Carborundum o. describes properties of their line of refractories.

82L Corrosion-Resistant Heat Exchangers. In bronze, copper, Monel, Inconel, carbon and stainless steels, nickel, and aluminum. Bulletin from Davis Engineering Corp.

83A Heat Transfer Medium. "Dowtherm" provides temperatures to 750° F. at pressures to 150 lb./sq.in. Information from Dow Chemical Co.

84L Furnace Castings. High nickel castings for extremely high temperatures and severe corrosive conditions. Duraloy Co.

85A Sulfur. Most of today's "Headline Products" require one or more sulfur derivatives for their production. Texas Gulf Sulphur Co.

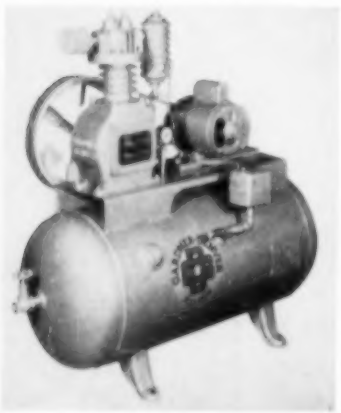
86L Rotary Positive Displacement Gas Meters. In capacities from 2,000 to 1,000,000 cu.ft./hr. Bulletin from Roots-Connersville Blower gives technical details.

87A Stainless Steel Plates and Heads. Plates, heads, rings, circles, flanges, forgings, bars, and sheets. Stock lists from G. O. Carlson, Inc.

88BL Heat Exchange and Process Equipment. Condensers, evaporators, mixers, reactors, pressure vessels, heat exchangers, reboilers, etc. Manning & Lewis Engineering Co.

89A Industrial Jet Equipment. "Chill-vactors," steam-jet evactors, fume scrubbers, special jet apparatus. Croll-Reynolds Co.

DEVELOPMENTS OF THE MONTH (Cont.)



381 Small Oil-free Air Compressor. Model CACB, product of the Gardner-Denver Co., is designed to provide oil-free air for the operation of instrument controls, as well as for use in food processing, brewing, distilling, paint spraying, and in the manufacture of plastics, etc.

Secret of the compressor is in the carbon parts in the cylinder which require no oil or water lubrication. The CACB is a single-stage, air-cooled unit which is available base or tank mounted. It supplies 4 to 5 cubic feet of oil-free air per minute, and is suitable for discharge pressures of 40 to 100 lb./sq.in.

Automatic start and stop controls are supplied as needed.

Complete details are available from the manufacturer. Circle number 381 on Data Post Card.

(Continued on page 64)

O CIRCLE *your Data Service requests on the handy postcard on page 54 to*

▶ GET *up-to-the-minute catalogs, data sheets and bulletins on new chemical products, processes and equipment.*

90L Vapor condensers. Niagara Aero Vapor Condensers give sustained full capacity in condensing vapors by evaporative cooling with only nominal use of water. Niagara Blower Co. Bulletin.

91A Filteraids. "Dicalite" filteraids are inert in acid and aqueous solutions and are both physically and chemically stable. Data from Dicalite Division, Great Lakes Carbon Corp.

92L Corrosion-Resistant Equipment. Heat exchangers, process tanks, fume ducts, piping, pumps, valves. Haveg Industries, Inc.

93A Titanium and Glassed Steel Equipment. Technical information from The Pfaudler Co.

94L Extended Surface Heat Exchangers. High efficiency, long service life, low maintenance. Aerofin Corp.

95A Methane Purification Plants. High purity, valuable by-products, automatic control, low power consumption, factory-assembled. Air Products, Inc.

96L Corrosion-Proof Materials. For tanks, floors, hoods, ducts, fume systems, plant interiors. Atlas Mineral Products Co.

97A Low Temperatures Separation Processes. High purity hydrogen, carbon monoxide, methane, ethylene, propane, nitrogen, from natural gas, refinery off-gases and coke-oven gas. American Air Liquide.

98BL By-Product Treatment. Booklet from Truland Chemical Co. describes facilities for refining of solvent mixtures or organic by-products.

99A Tubing for Atomic Power. Literature from Superior Tube Co. gives technical data on tubing in wide variety of analyses and sizes.

100L Filtration Analysis Report. Filtration tests at user's plant without obligation using samples of filter paper from Eaton-Dikeman Co.

101R Tantalum Test Kit. Corrosion test kit, available without charge to research technicians, contains both tantalum sheet and wire. Fansteel Metallurgical Corp.

102L Strainers. Twin strainers protect equipment without interrupting process flow. Details from Elliott Co.

(Continued on page 64)

a series about
PROCTOR SERVICES
for your new products

Mr. Albert G. Blank
Sales Manager
Process Industries Sales

No. 3: from product testing to guaranteed performance

PROCTOR'S guaranteed performance of equipment is based on carefully planned programs of drying tests.

This part of PROCTOR'S service to you represents an important value in your enlistment of PROCTOR service to solve your drying problem. It is a logical sequence to early work with your research team and the preliminary selection of drying methods discussed in our previous series.

This testing program has three main objectives: to establish wet-end processing needs; to determine optimum drying conditions in terms which can be readily translated into full scale equipment specifications; to verify, and very often to improve upon, product quality standards.

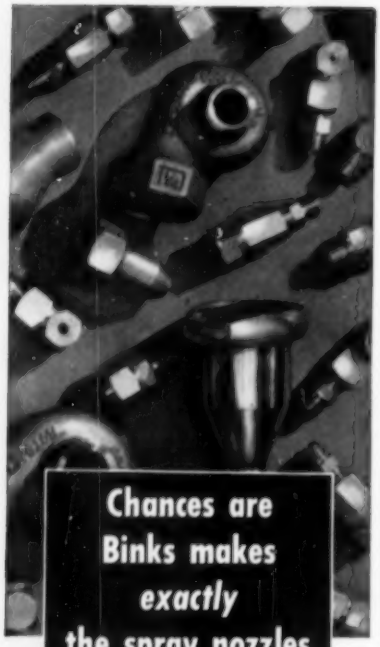
Therefore, three groups are involved: the manufacturer of wet processing machinery—filters, de-waterers, centrifuges; PROCTOR, with their proven background in drying; you, with specific knowledge of your product and your market. This "triangular" approach quickly leads to a program which is highly successful in the resolution of the drying problem.

Having conducted the tests themselves, either at PROCTOR'S engineering laboratory, as is usually the case, or under certain conditions, at the customer's plant, we come to the evaluation of the results. This is one of the areas where PROCTOR'S tremendous background in drying, exhibits its greatest value. PROCTOR'S techniques of evaluation, developed in thousands of drying studies, are proven by industry's wide acceptance and trust in the guarantee of performance that accompanies all PROCTOR drying equipment.

Your letter or call will avail you of these PROCTOR Services.

Proctor

PROCTOR & SCHWARTZ, INC.
PHILADELPHIA 20, PA.



Chances are Binks makes *exactly* the spray nozzles you need

for washing, cooling, processing, humidifying, dehydrating and hundreds of other applications.

Whatever your production or process requirements...you'll get the *right* spray nozzles quicker by calling Binks.

There is a size and spray pattern for every purpose...with nozzles cast or machined from standard or special corrosion-resistant metals and materials.

Send for Catalog 5600

Gives details on nozzle applications, sizes, capacities, spray patterns and metals. Easy to use selection tables.

Binks Manufacturing Company
3114-32 Carroll Ave., Chicago 12, Ill.

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A COMPLETE LINE OF INDUSTRIAL SPRAY NOZZLES AND COOLING TOWERS

MAIL COUPON NOW

PRODUCTS ADVERTISED IN THIS ISSUE (*Cont.*)

103TL Spray Nozzle Catalog. Comprehensive catalog from Spraying Systems Co.

103BL Gauge Glass and Cylinders. Complete stock of Pyrex tubular gauge glass and cylinders. Swift Glass Division, Swift Lubricator Co.

103R Motor Lubrication Booklet. Bulletin from U. S. Electrical Motors, Inc. gives data on advantages of "Lubriflush" system of motor lubrication.

104TL Engineering and Contracting Services. C. W. Nofsinger are engineers and contractors for the petroleum and chemical industries.

104BL Papers on Heat Transfer and Fluid Mechanics. Preprints of papers from June, 1957, meeting of Heat Transfer and Fluid Mechanics Institute. Stanford Univ. Press, Stanford, Calif.

105T Screw Engines. For oil-free handling of air and other gases. Flow rates from 350 to 15,900 cu.ft./min. Pressures to 155 lb./sq.in.abs. Gutehoffnungshütte (Foram Corp., representatives).

105BL Welded Aluminum Tanks. Also chemical processing equipment in aluminum, stainless and carbon steel, Monel and other alloys. R. D. Cole Manufacturing Co. Literature.

105BR Drum Reconditioning Machines. Gilco Traveler, Model 55-BHCL, simultaneously and automatically cleans inside and outside of used steel drums. Details from L. M. Gilbert Co.

106L Water Purification Equipment. Water stills, demineralizers, filters, for production of high-purity water. Catalogs and bulletins from Barnstead Still & Demineralizer Co.

107TL Steam Jacketed Gear Pumps. For heavy fuel oils, asphalt, etc. Bulletin from Schutte and Koerting Co.

107TR Laboratory Glassware. Diamond D Blue Line, product of Doerr Glass Co., offers quality and price advantages.

107BR Air Cooling Coils. Complete with multi-outlet expansion valves. Bulletins and prices from Rempe Co.

108L Single-Unit Flow Rate Regulators. For precision control of blending, liquid circuits, process additives, coolants. Technical bulletin from W. A. Kates Co.

109TR Ceramic-Insulated Thermocouples. Bulletin from Thermo Electric Co. describes line of "Ceramo" thermocouples for all types of process temperatures.

109BR Diaphragm Pumps. For corrosive, abrasive, viscous, thick, valuable, and easily-contaminated materials. T. Shriver & Co.

112BL Laboratory Air Control Equipment. Bulletin from Ace Glass, Inc.

113R Pilot Plant Rotary Dryer. Single shell, double shell, or steam-tube models. Complete information from Hardinge Co.

114L pH and Chlorine Control Handbook. Gives theory and application of pH control and describes line of equipment made by W. A. Taylor and Co.

114R Nickel Alloy Fabrication. Misco Fabricators, Inc. are designers, builders of heat-resisting alloy and stainless steel equipment.

122L Small Diameter Tubing. Stainless, nickel, and alloy tubing, tubular fabricated parts. Catalogs from J. Bishop & Co.

122BR Batch Mixers. 100 to 8,000 pounds per batch. Literature from H. C. Davis Sons' Mill Machinery Co.

122TR Radioactive, explosive, and toxic materials for sea disposal. Complete information from Crossroads Marine Disposal Corp.

123TR Valve Warmer or Cooler. Bulletin from Dean Thermo-Panel Coil Division, Dean Products, Inc., describes use of Dean Thermo-Panel Coil for many purposes.

123BR Pumps. Handle liquids, gases, slurries without corrosion or contamination. Catalog from Sigmamotor, Inc. describes models with capacities from 0.2 cc. per min. to 4.5 gal./min.

IBC Technical Planning Services. Economic studies, surveys, pilot plant, and engineering, etc. Ralph M. Parsons Co.

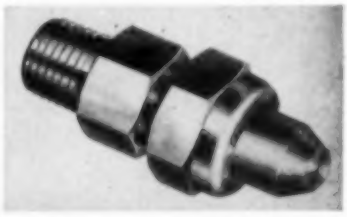
OBC Research department of Mixing Equipment Co is glad to cooperate in any work leading to more efficient fluid mixing.

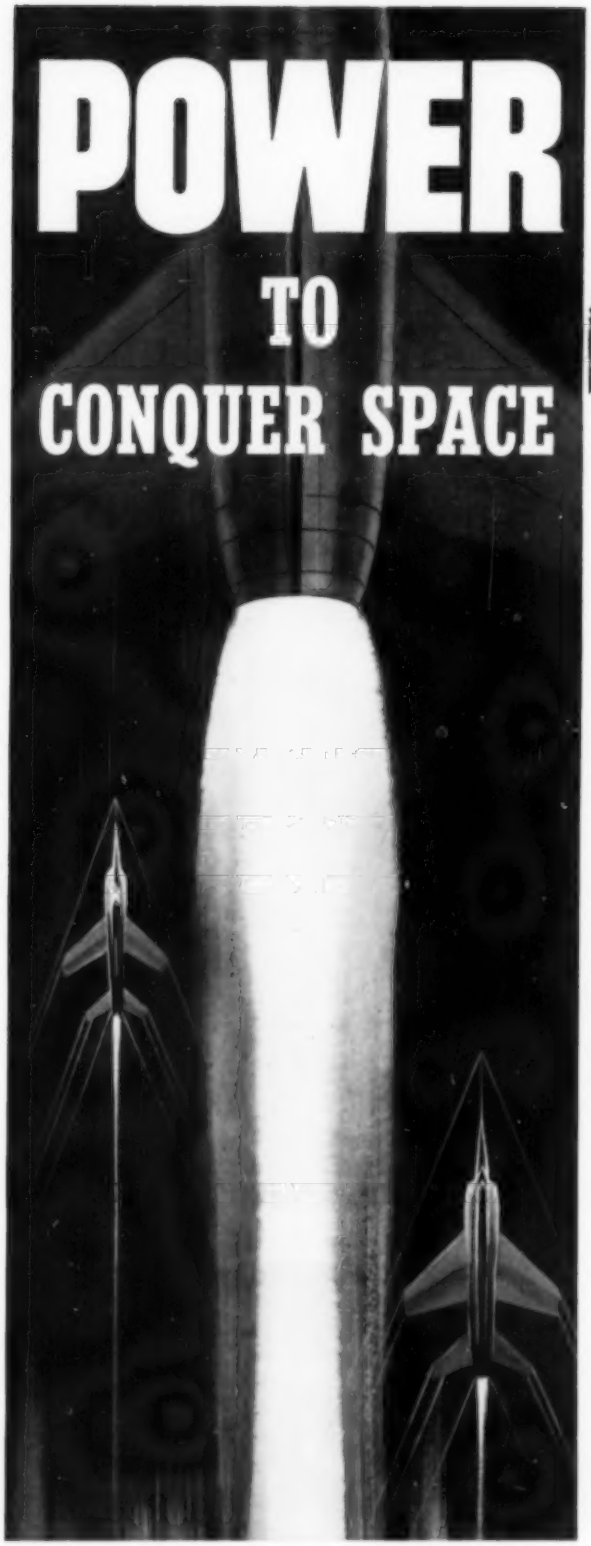
DEVELOPMENTS OF THE MONTH (*Cont.*)

382 Small Capacity Full Cone Nozzles. New group of full-cone nozzles, developed by the Spraying Systems Co., provides extremely small capacities and atomization using hydraulic pressure only.

Twelve different nozzles are offered, in capacities ranging from 0.042 gal./min. to 1.400 gal./min. at 20 lb./sq.in. Each nozzle is supplied complete with strainer.

Full-cone spray pattern of the nozzle is uniform in distribution and the spray angle ranges from 50 to 67 degrees as capacity increases. Data sheet is available with complete technical information from Spraying Systems Co. Circle number 382 on Data Post Card.





ADVANCED PROPULSION SYSTEMS and EQUIPMENT from a new subsidiary of CURTISS-WRIGHT

The successful development of aircraft and missiles to guard America's security demands the highest order of creative thinking plus a finely-tuned sense of responsibility. A unique blending of these essential qualities with the will and facilities for accomplishment enables Propulsion Research Corporation to solve propulsion problems created by fantastic speeds and altitudes.

Whether developing advanced propulsion systems or the smallest possible axial blower, PRC engineers and scientists work in teams in an intellectually stimulating environment. Projects receive the benefit of impressive resources in research, analysis, design, prototype fabrication and test, and manufacture.

Current programs include engineering, research and development in the turbo machinery and related fields, and development and production of aircraft accessories. Underway are projects in specialized centrifugal and axial flow blower fans, turbo pumps, turbines, fluid pumps, valves, auxiliary power units and cabin conditioning units.

In solving critical technical problems of precision components for aircraft and missiles, PRC is pacing America's progress in the air . . . and into space!

PROPULSION RESEARCH CORPORATION
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Divisions and Wholly Owned Subsidiaries of Curtiss-Wright Corporation:

Wright Aeronautical Division, *Wood-Ridge, N. J.* • Propeller Division, *Caldwell, N. J.* • Plastics Division, *Quehanna, Pa.* • Electronics Division, *Carlstadt, N. J.* Metals Processing Division, *Buffalo, N. Y.* • Specialties Division, *Wood-Ridge, N. J.* • Utica-Bend Corporation, *Utica, Mich.* • Export Division, *New York, N. Y.* Caldwell Wright Division, *Caldwell, N. J.* • Aerophysics Development Corporation, *Santa Barbara, Calif.* • Research Division, *Clifton, N. J.* & *Quehanna, Pa.* Industrial and Scientific Products Division, *Caldwell, N. J.* • Curtiss-Wright Europa, *N. V., Amsterdam, The Netherlands* • Turbomotor Division, *Princeton, N. J.* Marquette Metal Products Division, *Cleveland, Ohio* • Curtiss-Wright of Canada Ltd., *Montreal, Canada* • Propulsion Research Corporation, *Santa Monica, Calif.*

The Foxboro M/58 Consotrol Controller (shown full size, without cover). Can be panel-mounted on Consotrol Control Station, or field-mounted.

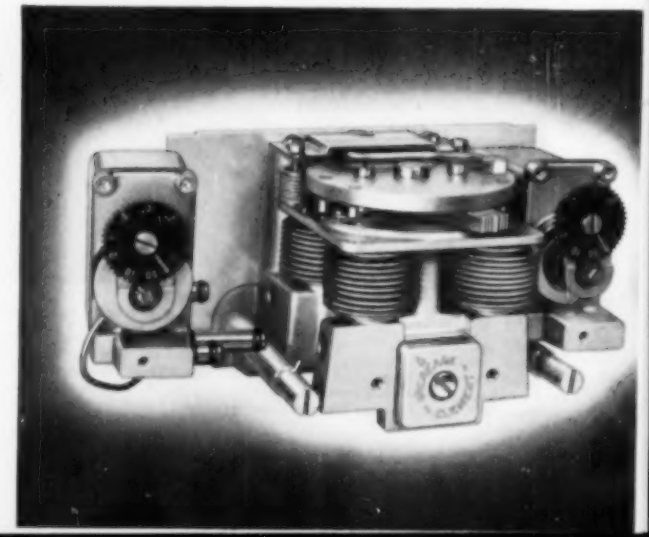
THE FOXBORO M/58 CONSOTROL

The M/58 Controller's Revolutionary Floating Disc System

Here's the exclusive Foxboro design development that gives M/58 Control its unique versatility, precision, and stability. The floating disc and matched bellows assure uniformly high controller sensitivity and pin-point control action, even at widest settings of the proportional band. Lever-set proportional band adjustment is calibrated to 500%.

Component Construction Gives Unrivaled Versatility

Not only is the complete controller easily detachable as a unit, but also, each component is a "plug-in" unit. For example, reset plugs in at right as shown; derivative, similarly, at left. All 4 control actions, with 2 reset ranges, are available and easily adjustable to widest variations in operating conditions. Proportional action from 1 to 500% quickly set by lever.



Outperforms all other controllers!

...the controller with the FLOATING DISC

If you think this claim is exaggerated, just put a Foxboro M/58 Consotrol* Controller on your process. The tougher the job, the more it will outperform other controllers! Or ask any present user . . . many of the largest, most progressive petroleum and chemical processors are using hundreds of these instruments. They will unhesitatingly confirm that this exclusive Foxoboro development has put their processes "on stream", automatically and smoothly from the control room, without false starts or confusion.

The M/58 Controller can do the same for your process. The flexibility of its control functions makes it readily adaptable to *all* processing techniques. All four actions are available, with two ranges of reset . . . all are easily adjustable to the most widely varying operating conditions. For example, reset and derivative functions plug in . . . proportional action from 1 to 500% can be quickly set by a lever. And calibration is a simple zero adjustment!

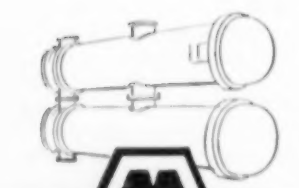
Get full details on this simple, truly "universal" Controller. Write for Bulletin 13-19 and ask your Foxboro Sales Engineer for a demonstration. **The Foxboro Company, 936 Neponset Ave., Foxboro, Mass., U.S.A.**

*Reg. U.S. Pat. Off.

FOXBORO CONSOTROL INSTRUMENTS

Reg. U.S. Pat. Off.

Any Size...Any Design



Size or complexity makes no difference to the prompt and efficient service that The M. W. Kellogg Company offers to the process industries on heat exchangers. Whether it's an order for a single 14-ft. diameter giant, like the one above, or a group of normal size units, Kellogg's recently expanded facilities are geared to produce to the strictest design standards and delivery schedules. With these facilities, Kellogg can handle the complete job of designing, engineering, and fabricating heat exchangers, or make exchangers to customers' own designs.

FABRICATED PRODUCTS DIVISION

THE M. W. KELLOGG COMPANY

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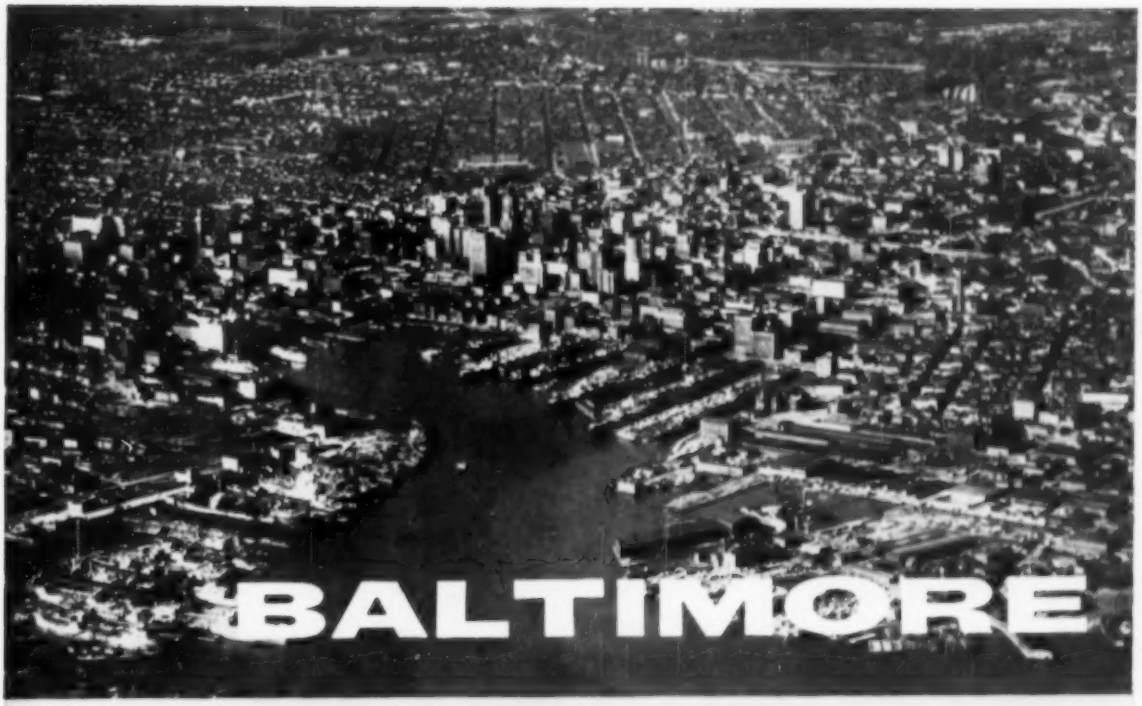


—THE CHEMICAL ENGINEER'S SEPTEMBER OYSTER

J. R. Mecredy and W. K. O'Loughlin | **Davison Chemical Corporation, Baltimore, Maryland**

- **For the Historical Man—Fort McHenry, Civil War battlefields.**
- **For the Inner Man—oysters, soft-shell crabs, best eating in the East.**
- **For the Technical Man—a major chemical area, another great technical program, and Wilmington 60 miles away.**
- **For the Sportin' Man—major league baseball, fishing, swimming.**

Baltimore in September! The best time of year in Maryland, and A.I.Ch.E. is going there for its National Meeting September 15-18. World famous sea-food. Fishing, swimming, boating on Chesapeake Bay. Fort McHenry, where "the rocket's red glare" gave proof that the young Republic's flag was still there, continues to epitomize the historical lore of this legendary border state.

But now the beautiful old city has acquired both a major league baseball team and a major chemical industry. Baseball for the lighter side, chemical industry for the serious interest.

Today the nation's eighth largest city has major portions of the chemical industry in titanium dioxide, chromium chemicals, steel, petroleum catalysts, sulfuric acid, fertilizers, petroleum refining, organics, and more. Baltimore is now the nation's second largest port in terms of foreign trade, is a major industrial center. The magnificent port area is lined for miles by chemical works, giant ship yards (shades of the once world-famous Baltimore Clippers that helped build our nation's wealth), steel mills (Bethlehem's Sparrows Point mill is the largest tidewater steel plant in the world), metal working plants, refineries, and hundreds of factories which process foodstuffs and raw materials brought into the port from all corners of the world.

A Town Grown Large

Industrial city, yes, but Baltimore has not changed that much: it is still proud to be a warm, hospitable Southern town—much more a town than a city for all its size and million and a half population. The pleasures of a town with the advantages of a city—that is Baltimore.

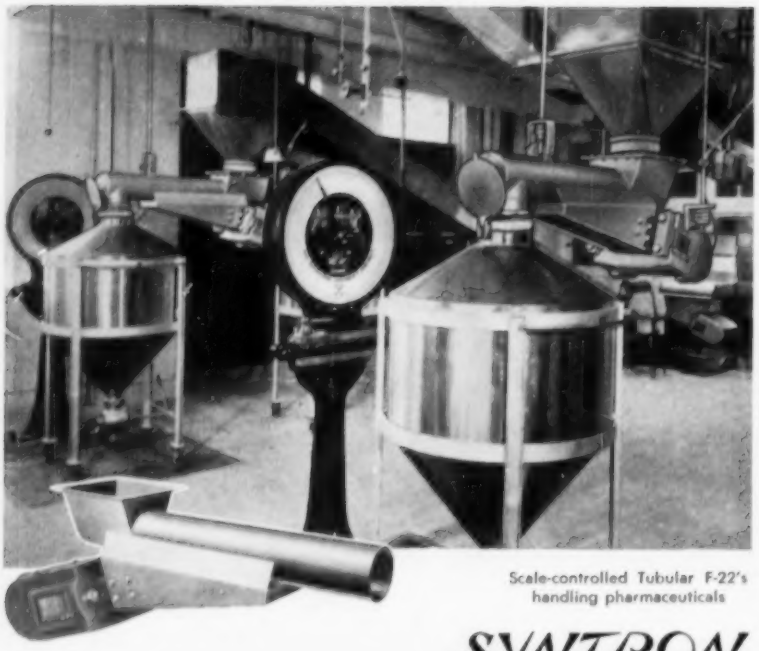
The hotels are all close together so you do not have to worry about getting into the headquarters hotel, and since Fall is the best season in Baltimore, a little walking in the Chesapeake Bay air is just what the doctor ordered.

For the gourmet, Baltimore just about invented "southern" coastal cooking. No need to exaggerate—just ask a Philadelphia man (or a New Yorker for that matter) why he drives all the way to Baltimore for some of those renowned "eastern shore" soft-shell crabs. Then there's the Maryland-fried chicken (not just "southern-fried"—this is special), and the exquisite diamond-back terrapin and green turtle soups, Chesapeake Bay oysters, and the fish—bluefish, striped bass (called rockfish) down here. These are just the cornerstones of Baltimore cuisine—everything else is here, too. The restaurants are famous, historic, have been in the business of pleasing the palate for generations, some still being operated by the original families.

Valley Forge to Antietam

Historically, Baltimore could be called the Boston of the south (except both Boston and Baltimore would probably hate us). It was here, of course, that the flag flew over Fort McHenry in the War of 1812 so that Francis Scott Key, on one of the bombarding British battleships, could see it still there by the dawn's early light and

(Continued on page 70)



Scale-controlled Tubular F-22's handling pharmaceuticals

SYNTRON
Vibra-Flow

VIBRATORY FEEDERS

Smooth, even bulk materials flow, with variable control

Match the capacity of your processing equipment—eliminate erratic underfeed and overfeed—smooth out production cycles.

SYNTRON "Vibra-Flow" Vibratory Feeders fill the gap between storage and processing. They provide a smooth, even flow of bulk materials—hot or cold, dry or damp, from powders to chunks—to mixers, batchers, driers, cooling and other types of processing equipment. And, what is most important, the flow rate is instantly adjustable, from minimum to maximum to meet production schedule changes.

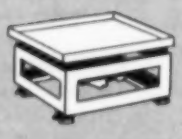
Investigate the production possibilities obtainable with SYNTRON Vibratory Feeders in your operation. Send us the details of your problem—our application engineers will be glad to submit recommendations.

Builders of quality equipment for more than a Quarter-Century.

Other SYNTRON Equipment of proven Dependable Quality

HOPPER LEVEL SWITCHES

PACKERS AND JOLTERS



FLOW CONTROL VALVES

Write for complete catalog data — FREE

SYNTRON COMPANY
116 Lexington Avenue — Homer City, Penna.

BALTIMORE

(Continued from page 69)

know Baltimore fought on. And the Fort is still there, a ten-minute ride from the heart of the city. It has changed little since 1812, all its old cannon, fortifications, dungeons, and tunnels are much as they were when our National Anthem was born.

The city abounds in points of interest. There is the B & O Transportation Museum which houses a remarkable collection of ancient engines and cars in America's first railroad station. There is the grave of Baltimore's dark poet Edgar Allen Poe, as well as the house in which he lived, which is now a shrine. The historic shot tower preserves the method our forefathers used to make their much-needed bullets. A city of churches, the first Unitarian church in the country is here, and nearby is the first Roman Catholic Cathedral in America. Known as the Monumental City, Baltimore has the first monument built to the memory of George Washington. The Walters Art Gallery is here and the fast-growing Baltimore Museum of Art. The first dental school in America is now part of the U. of Maryland, and the world-respected Johns Hopkins Univ., renowned for its documentary TV programs on science, is a major center of chemical engineering as well as a remarkable cultural center.

Maryland is a beautiful state—rolling green fields, a gracious country often compared to the best of English countryside with its meadows and old fences—so why not leave the city on some side trips? The imposing Naval Academy is in nearby Annapolis right next to the world's longest bridge—the Chesapeake Bay Bridge—a mere seven and a half miles long! Washington is 35 miles away. Wilmington is 60 miles. For the historical minded, Gettysburg is a short 40 miles north, Antietam is 55 miles west, Manassas (Bull Run) only 58 miles southwest. Valley Forge is 90 miles north near Philadelphia. Mount Vernon is down just beyond Washington about 40 miles away.

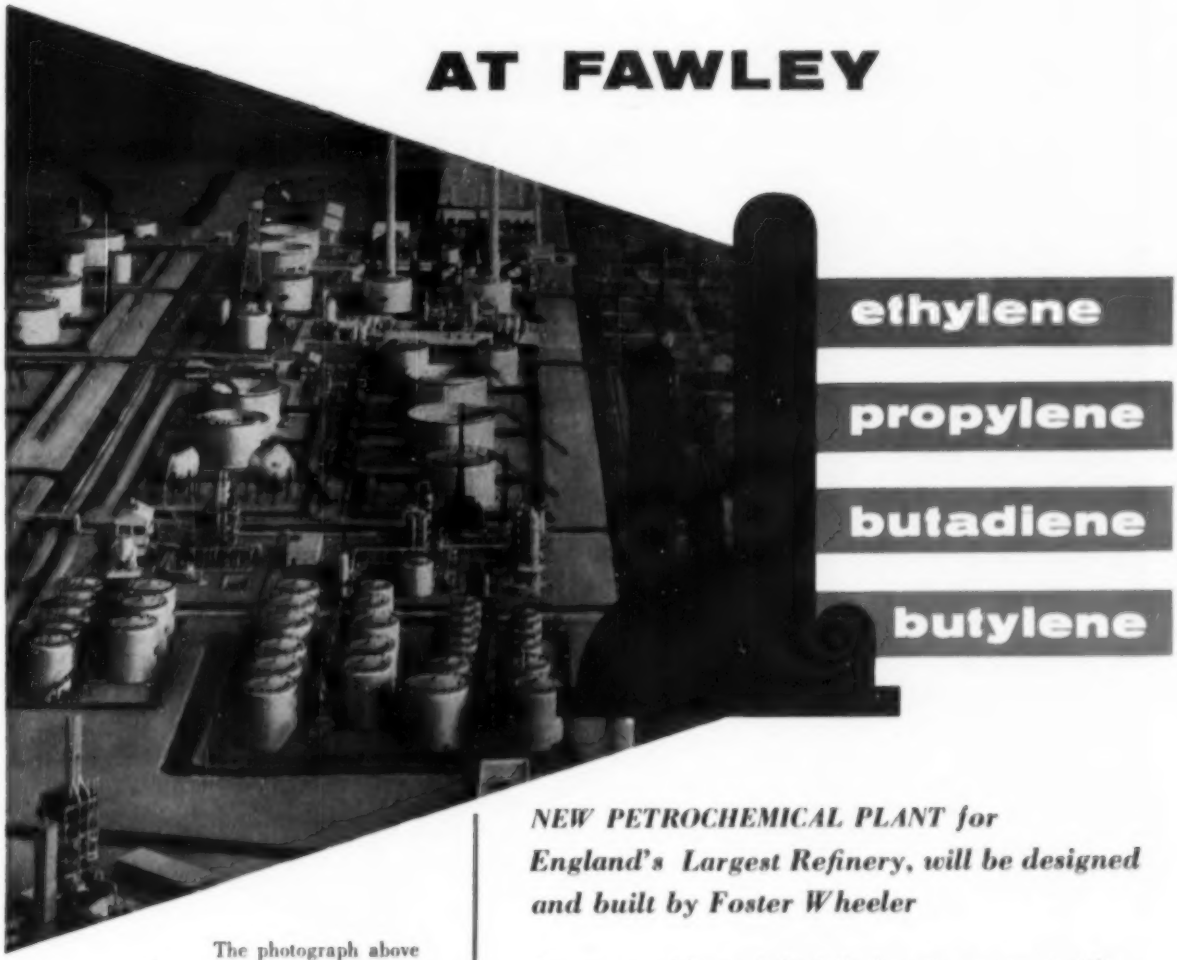
Technical Program

Want to catch up on the latest technology in *jet propulsion?* It's going to change the character of the fuels, lubricants, and other chemicals required from the chemical industry. Glenn L. Martin (of Baltimore, of course) is one of the major companies already deep in "Project Vanguard" and one symposium will cover many chemical engineering aspects of the launching of the space satellite. Another session will

(Continued on page 72)

petrochemicals

AT FAWLEY



The photograph above shows a scale model of part of the huge Fawley Refinery of Esso Petroleum Company Limited. Foster Wheeler was the prime contractor for this complete "grass roots" refinery. It now has twenty-one process units and more are projected.

Foster Wheeler designs and builds petroleum, chemical and petrochemical processing plants anywhere in the world.

NEW PETROCHEMICAL PLANT for England's Largest Refinery, will be designed and built by Foster Wheeler

SYNTHETIC rubber and plastic hydrocarbon raw materials (ethylene, propylene, butylene and butadiene) will be produced from 250,000 tons per year of petroleum intermediates in a major process installation at the Fawley, England, refinery of Esso Petroleum Company Limited. Foster Wheeler, who built the new Fawley petroleum refinery, the largest in England, will also provide mechanical design and construction for this petrochemical project. Esso Research and Engineering Company supplied basic process design data.

These basic hydrocarbon products represent a new and very substantial source of raw material for the British synthetic rubber and plastic industries.

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OFFICES IN PRINCIPAL INDUSTRIAL CITIES

BALTIMORE

(*Continued from page 70*)

go deep into newly released information on high energy fuels. This is going to be a *must* symposium.

How about *direct operating labor costs?* The estimation of direct operating labor is closely related to the chemical engineer's work with estimations for capital appropriations requests for new process facilities. Such items as maintenance, payroll burden, superintendence, and various overheads are all often pro-rated from the direct operating labor estimate. The increasing trend toward automation brings all of this into important consideration as to just what the proportional expense of operating labor in a plant versus added capital investment in automatic control devices should be. This symposium is aimed at trying to formulate and answer some of these questions. You had better hear it—there is very little guidance any where else.

LADIES—MEET THE GOVERNOR!

When you think of Baltimore you think of Lady Baltimore and Baltimore thinks of the ladies!

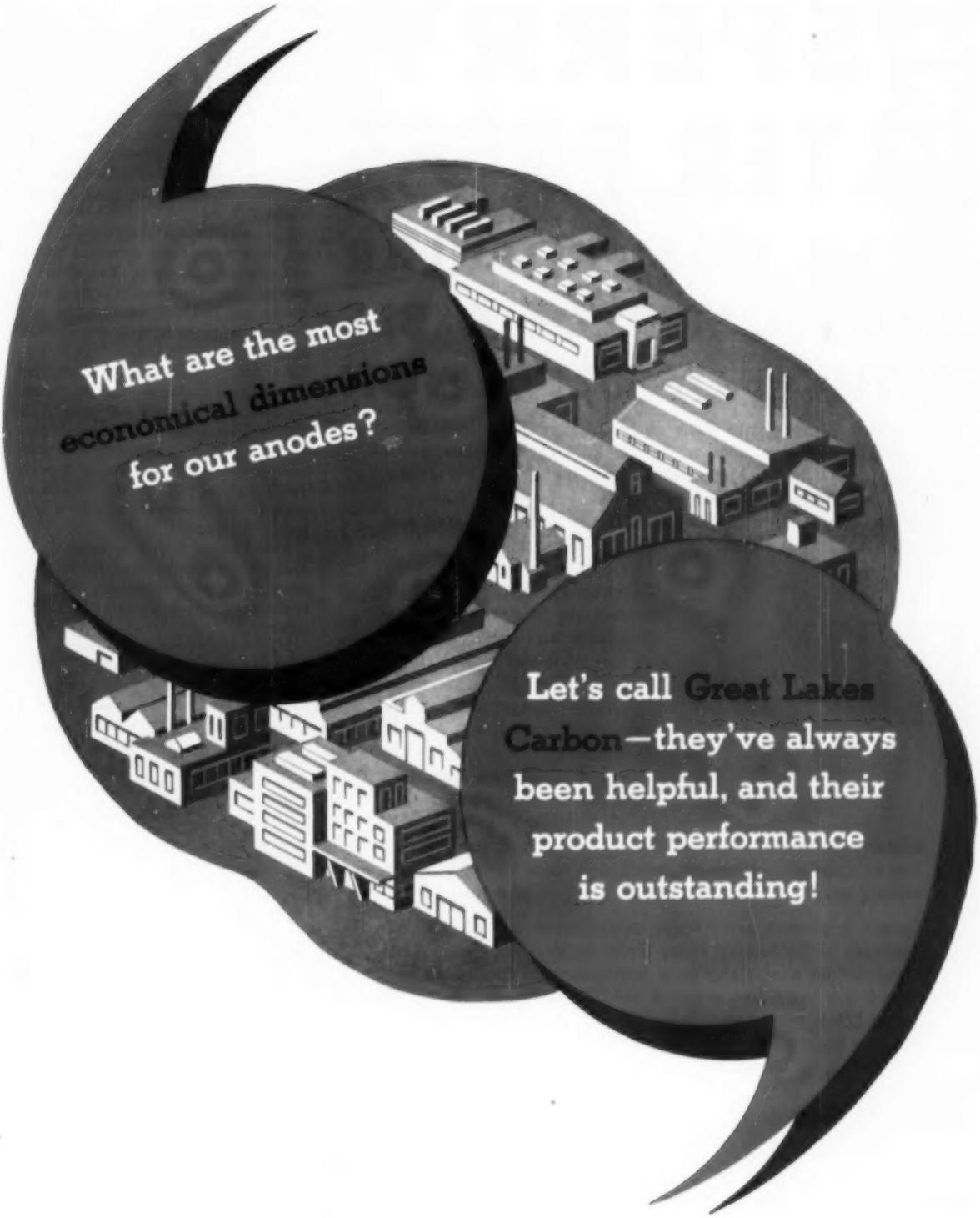
Main Event: afternoon tea with Maryland's famous Governor, The Hon. Theodore R. McKeldin.

Other highlights: the coffee hour each morning, a trip through the huge McCormick and Co.'s spice and tea plant; a trip to historic Annapolis with luncheon at a famous restaurant, and all the time for socializing and shopping you could want. Of course, the ladies are expected to provide the "real" atmosphere on the boat trip and at the banquet.

Is there any company in the industry which isn't thinking of *possible foreign plants?* If so, we don't know one. The time is here when American firms just have to branch out abroad, but how many are wondering just how to go about it if at all? Then there's the problem of getting good men to go abroad. It's not a cut-and-dried matter. More and more chemical engineers are running head-on into problems of establishing foreign plants every day. At Baltimore the committee has gathered a panel of experts in many aspects of this problem, will turn them loose for discussion and your questions.

There is little doubt that our chemical industry is becoming more aware and more concerned in the matter of *plant safety.* No two industries have a bigger problem, more universally applicable, than the liquid air and ammonia industries. Representatives of operating groups in both industries will

(*Continued on page 74*)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Let's call Great Lakes Carbon—they've always been helpful, and their product performance is outstanding!

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GREAT LAKES CARBON CORPORATION

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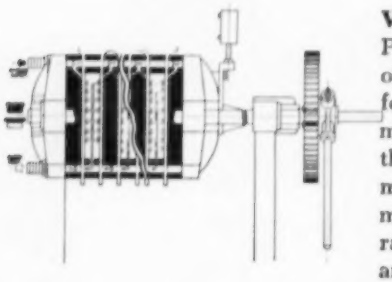

Versatility—Sperry Filter Presses are made in a variety of models and capacities . . . for use with any type of filter media or filter aid . . . to handle the widest range of filterable mixtures, including viscous materials . . . under a wide range of operating pressures and controlled temperatures.

Economy—Sperry Filter Presses are low in first cost . . . low in upkeep . . . low in installation costs . . . low in operating costs . . . low in depreciation . . . and long in life.

Sperry engineers are always available to put all the advantages of the Sperry Filter Press to work for you. Write today for an analysis of your particular filtration problems, or ask for your free copy of the SPERRY FILTRATION CATALOG, containing specifications and other technical data for your reference.

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BALTIMORE

(*Continued from page 72*)

be in Baltimore to give you the latest on modern safety practice. On the plant trips, and there will be many, you can see actual safety practices that have helped set safety records in such diverse industries as fertilizers, sulfuric acid, chrome chemicals, distilling, and more.

The *chlorine and alkali* produced in our electrolysis units threatens to get seriously out of balance. The effects of such an imbalance would have a wide impact and you will not want to miss the current facts, figures, and theories on this situation.

At the symposium on *materials separations by adsorption, dialysis, and ion exchange*, you will find some of the new uses being devised for these technologies, uses that may very well solve some problems you have been "chewing over" back at your plant. You'll go home from this symposium with a notebook full of facts.

Take *drying* for a minute. Some claim it's a pretty "dry" subject, but name the indstry where the efficiency and cost of this basic operation is not important!

How about *low-temperature processing?* Modern plants are now taking much more advantage of this means for handling sensitive materials or reactions. Come to Baltimore and learn the current trends, as continued from the session at Boston (the basis for *CEP's* Special Feature theme of this issue).

Bonus: The Student Activities Committee has planned something new and interesting for the younger members of the profession. (Do you perhaps have a boy taking his first steps in chemical engineering? Bring him along—with the rest of the family, of course. Don't forget the season-end vacation). There will be sessions for the students, reduced registration fees, and some planned social functions.

That Summer-End Holiday

All-in-all, Baltimore is offering a pretty fine four days (or more). This is another meeting for the family. If the food, history, swimming, fishing, and technical program don't bring you, how about a Sunday doubleheader between Cleveland and Baltimore for you baseball *aficionados*? (Cleveland and the White Sox will be here for night games during the meeting, too.) Still want more? Well, there will be a first-rate social program planned, topped-off by a chemical engineers' steamer trip down Chesapeake Bay complete with sight-seeing, dinner, sea breezes, and an orchestra for dancing all evening.

J. L.
Did these centrifuges
Come up to expectations
in our plant?
W. K.

RING
UMMARY REPORT

SUBJECT: Test Program—Sharples Super-D-Hydrator for recovery of sodium chlorate crystals.

MATERIAL: Slurry from evaporative crystallizer. (25% concentration)

OBJECTIVES: Recovery of sodium chlorate crystals with:
(1) Minimum moisture (1.5%)
(2) Minimum chloride impurities (.03% max.)
(3) Minimum crystal breakage
(4) Maximum capacity

RESULTS: Tests on C-27 Super-D-Hydrator produced the following:
(1) Residual moisture 1.5%
(2) Chloride impurities .015%
(3) Vibrator leveler minimized breakage
(4) Capacity 5,500 lbs/hr.
(5) Rinse water only 3% of weight of crystals

ACTION: Tests highly successful. Recommend purchase of two Super-D-Hydrators for present plant. Indicated also for contemplated plants.

You bet-we're getting 7500-8000 lbs./hr. regularly instead of 5500. Suggest new Sharples model with quick-opening doors for expansion program.
J. L.

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SALARY SURVEY OF ENGINEERS IN CONSULTING FIRMS

New, detailed survey of the salaries of engineers employed by 311 consulting firms shows:

- **Salary advances as experience increases.**
- **Median salaries at the various levels of experience.**
- **The wide spread of salaries, with interesting peaks, among engineers with similar experience and position.**

A new salary survey * is based on a questionnaire answered by 6,407 engineers of all types employed by 311 consulting engineering firms. The average number of engineers employed by the surveyed firms is 20.6. Engineers are defined in the survey as "all engaged in engineering work at the level which requires knowledge of engineering, physical, natural or mathematical sciences equivalent to at least that acquired through completion of a four-year professional college course." Technicians, draughtsmen, etc., are excluded.

The survey is a *salary* survey and not an *income* survey. It does not include bonus pay, overtime pay if any, the profits of owners or partners, stock plans, etc.

The detailed results of the survey have been coordinated and tabulated in the table. Broken down according to eight grades of job position and experience (see box for description of grades), the table shows monthly salaries of the engineers at narrow $50 intervals and the percentage of engineers at each level within each grade.

* Survey just made and published by the National Society of Professional Engineers.

DEFINITION OF GRADES

Grade	Typical Positions
1. . . .	Junior engineer
2. . . .	Junior engineer, party chief, instrumentman, quantity estimator, etc.
3. . . .	Junior engineer, design draftsman, engineering instructor, etc.
4. . . .	Resident, project, office, design, test, or process engineer, etc.
5. . . .	Project, senior office, senior design, senior test or process engineer, etc.
6. . . .	Division or district engineer, production engineer, etc.
7. . . .	Chief engineer, assistant chief, director of research, etc.
8. . . .	Chief engineer, director of research, etc.

CONSULTING ENGINEERS' SALARIES—RANGE AND MEDIAN

Per Cent of Engineers in Salary Range

Monthly Salary	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8
Over $2000								3.4
1951-2000								4.5
1601-1950							0.4	0.0
1551-1600							6.9	0.0
1501-1550						0.4	1.7	3.4
1451-1500						0.4	0.0	9.0
1301-1450						0.0	0.9	0.0
1251-1300						0.7	0.0	4.5
1201-1250					0.1	0.0	9.9	3.4
1151-1200					1.3	3.4	3.5	5.6
1101-1150					0.0	0.0	3.5	1.1
1051-1100					0.0	1.1	11.3	2.2
1001-1050					0.0	4.1	0.0	9.0
951-1000					1.5	2.6	22.1	14.7
901-950					5.9	3.5	5.2	4.5
851-900				0.1	14.0	8.9	3.0	6.7
801-850				0.0	4.8	14.3	7.8	5.6
751-800		0.1	0.1	8.3	5.1	16.4	6.9	0.0
701-750		0.0	0.0	11.2	3.1	22.2	7.8	18.0
651-700	0.0	0.3	5.9	9.4	16.9	9.9	2.2	2.2
601-650	0.2	4.4	4.6	15.3	20.5	8.2	1.7	1.1
551-600	0.2	1.4	26.6	14.9	19.7	2.0	4.8	1.1
501-550	1.2	7.5	13.7	27.3	5.1	1.5	0.4	
451-500	4.8	27.1	21.2	10.4	1.7	0.2		
401-450	33.6	26.2	23.3	2.4	0.1	0.2		
351-400	11.7	19.2	4.1	0.7	0.2			
301-350	38.0	10.8	0.3					
251-300	6.7	1.9	0.2					
201-250	3.6	1.1						
Under 200								
Median Salary	358.00	433.55	504.40	582.12	657.70	768.89	947.02	987.54

Who Was Surveyed

The engineers in the accompanying table are all employed by consulting firms, are all salaried. No owners, partners, or technicians are included Of the 6,407 surveyed, 40.9 per cent (2,624) are registered, 53.9 per cent are in the top five grades, only 5 per cent are in the top two grades. Analyzing the grades, we see that the bulk of engineers answering the survey are professional engineers of considerable experience but below the level of management.

Of the firms reporting, 79.1 per cent have 20 or fewer engineers on the payroll, 79.4 per cent do business in cities larger than 50,000 population, and 63 per cent are located east of the Mississippi (with another 15.1 per cent in the Southwest).

When the figures given by the surveyed engineers are tabulated into the table, certain facts are immediately clear. First, the steady "step-up" in pay as experience increases—which is shown both by the upward movement of the bars and the ascending line of the median. Second, as experience increases there is a tendency for the range of salaries paid to grow wider—shown by the growth in size of the bars. In turn this indicates that, compared to the median, the engineers on the lower pay levels tend to rise more slowly, and those on the top levels of pay rise more quickly, giving a definite widening of salary differential in the higher grades. Perhaps the most important fact disclosed by this survey is the very wide *range* of salaries within a single grade. But this is opposed by the tendency for large percentages of engineers to be at particular salary levels within a given grade.

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Liquid Level CONTROLS

For use as high and low limit switches, to sound alarms, flash signal lights, start or stop fluid transfer pumps, or to operate control valves.

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Series 2800 are dependable, inexpensive, snap acting liquid level controls. They are float actuated and, for maximum versatility, are available with either electric (explosion-proof) or pneumatic switch action. Either pilot type is interchangeable on the same float housing assembly. Stab-in type of tank mounting provides easy installation. Available with 4" iron or steel flanged tank connection. Write for Bulletin F-2800 for complete information.

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Memo: to all process engineers—

Why Tolerate Liquid Carry-Over?

...when METEX Hi-Thruput Mist Eliminators can deliver 100% efficiency!

● Whether it's on a vertical tube evaporator, a packed column, knock-out drum or a vacuum pipe still, there's no necessity, *today*, to permit poor liquid-vapor separation to pull product quality and profits down. With Metex, you have a unit that's *different*. Hundreds of thousands of openings and wire surfaces, so combined as to baffle uprising gas-liquid streams in multiples of thousands of physical separating contacts, can and *do effect complete gas-liquid-contaminant separation*.

No other unit delivers more efficiency, offers longer life or less maintenance. Used and specified by hundreds of process engineers, Metex Hi-Thruput Mist Eliminators are the standard of excellence wherever efficient entrainment separation is important to good production and profits.

• Write for Bulletin ME-6

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Representatives in principal cities throughout the world.

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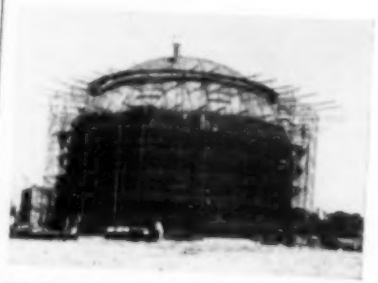
NUCLEAR NEWS

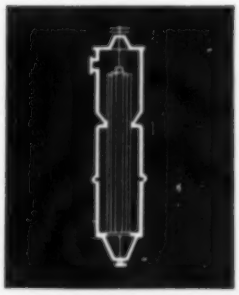
Revived interest in the use of flowing solid particles for nuclear fuels is in the works under a new contract awarded by AEC to Fluor Corp. Although Fluor's findings are not yet established, the company believes that the new reactor system, based on the flowable solids fuel concept, will operate with less fuel enrichment, at higher temperature and lower reactor pressures, and will involve less corrosion in the reactor system. Object of the contract is to test and develop the new fuels. □

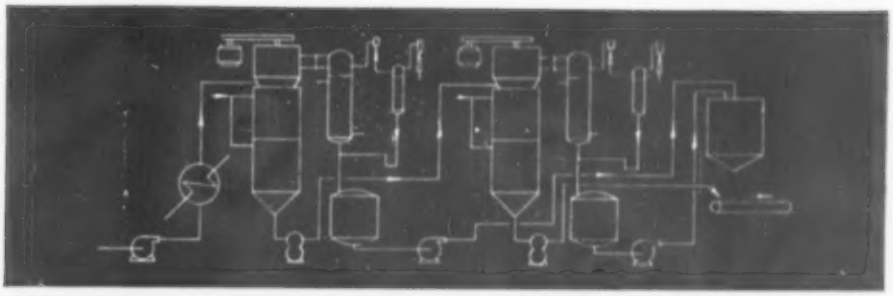
An engineering and development contract for the development of a vessel impervious to molten fused salts has been awarded to Horizons, Inc., of Cleveland, by the Argonne National Laboratory. Argonne needs such a vessel for its recently developed Fluoride Volatility Process for the reprocessing of nuclear fuels (See *CEP* February, 1957, p. 72-F for details of the process), since corrosive fused salts used in the process attack the metal walls of the vessels in which the process is carried out. □

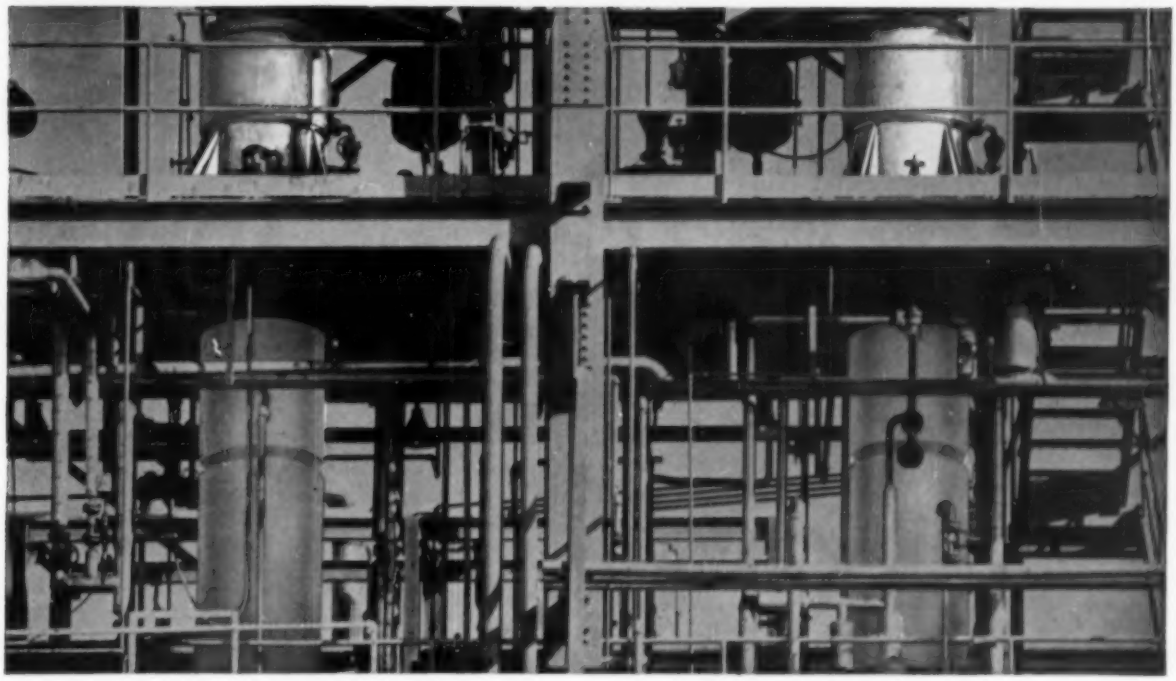
The first sodium cooled "thermal" reactor to go critical is the Sodium Reactor Experiment, a small-scale experimental civilian atomic power project being developed for the Atomic Energy Commission near Los Angeles by Atomics International, a division of North American Aviation, Inc. During its initial start-up test the SRE operated at a power level of about one kw. of heat and no electricity was generated. Design capacity of SRE is 20,000 kw. of heat. □



This huge airtight cylinder of steel topped by a dome is the reactor shell of Argonne National Laboratory's Experimental Boiling Water Reactor which has just gone into operation. Almost half the reactor shell is below ground. The part of the shell above ground is shown here in the process of being covered with a layer of 3-inch thick blocks of Pittsburgh Corning Corp.'s Foamglas insulation. The shell serves both to contain radioactive gases in the highly unlikely event of an explosion, and as insulated enclosure for the air-conditioned interior.







Turba-Film Processor produces epoxy compounds at Shell

The chemical and processing industries recognize that good engineering is just as important as good equipment. In recent years, Rodney Hunt has accumulated broad experience in specialized applications of the Turba-Film® Processor as well as in completely engineered package systems.

Shell Chemical Corporation produces petroleum-based resins at its plant near Houston, Texas. The process involves removal of the solvent carrier to give a dry epoxy compound. Rodney Hunt engineers proved the patented Turba-Film Processor ideal for this application. The Turba-Film permits a high degree of solvent removal with greater through-put than conventional equipment. Solvent and carrier pass through two Turba-Film units as a thin, falling film. Localized overheating is eliminated and product color is greatly improved.

Are you concerned with deaeration, deodorization, esterification, concentration, stripping, distillation, evaporation or other processing operations? Chances are good that Rodney Hunt can give you profitable answers to your problems.

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*Pioneer and world leader in the development and manufacture of precision viscosity instruments. Today, Brookfield is universally accepted as the World's *Standard for Viscosity Measurement and Control!*

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ENGINEERING LABORATORIES INCORPORATED

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AEC BUYING MAJOR QUANTITIES OF LITHIUM HYDROXIDE

The Atomic Energy Commission has just authorized release of details of its contracts with three major lithium producers. Not released is the quantity involved or AEC's end use for the lithium, but the information shows that the Commission is principally interested in lithium-6, one of the two naturally occurring isotopes.

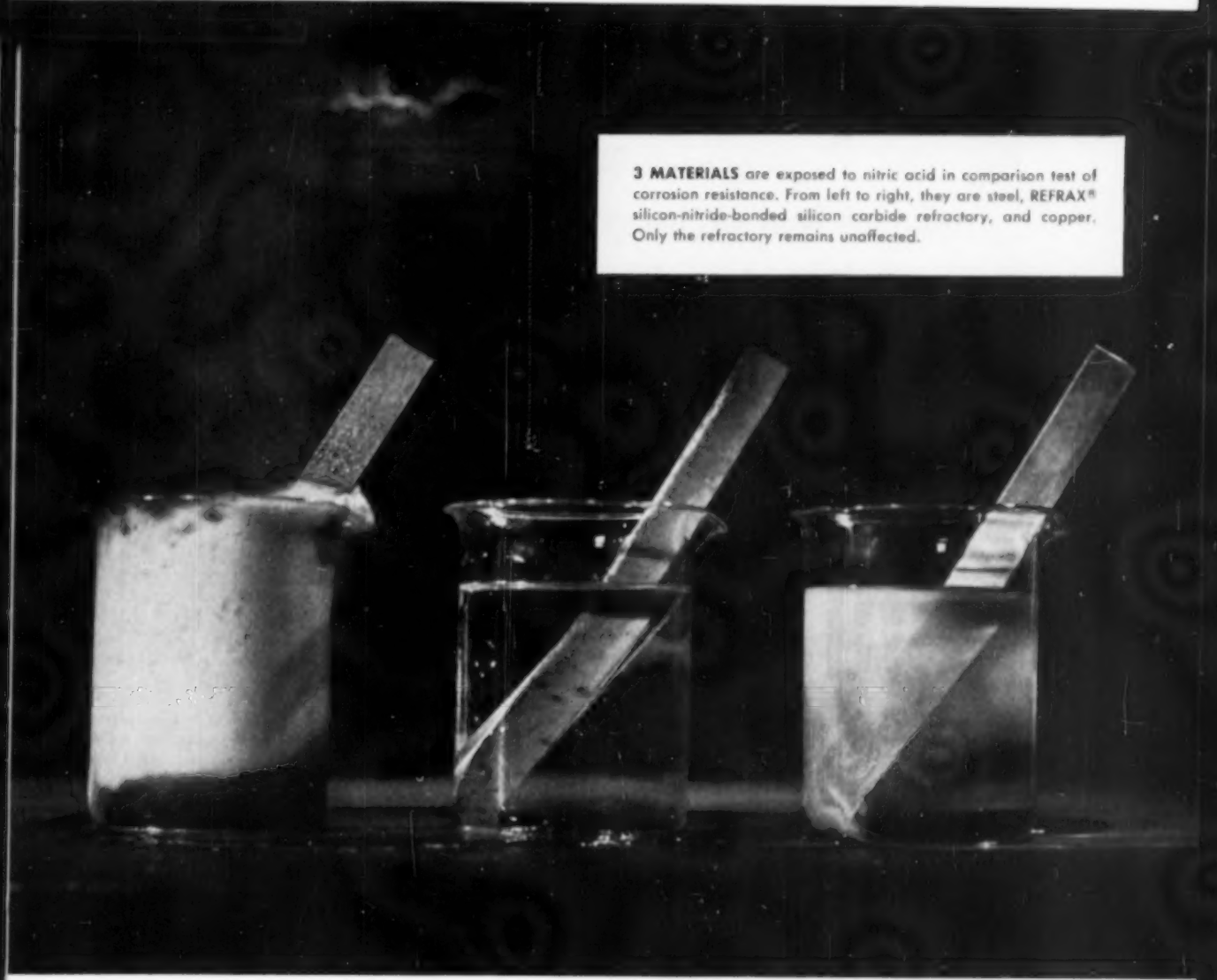
At present the three major lithium producers are supplying "virgin" lithium hydroxide to the Commission, and the "tails" (material from which the lithium-6 has been removed) are available only to the original producers in the same proportion in which it was supplied. Chemically, the tails are identical to virgin lithium hydroxide. The importance of this to commercial users of lithium is obvious; the tails are available for commercial use despite the contractual arrangements with AEC. The suppliers are not obliged to buy back the lithium hydroxide at any predetermined rate, and AEC is committed to withhold sale of any unreturned lithium for 10 years after completion of the current contract, which protects the lithium producers from competing with a Government stockpile.

Unique nuclear reactor project aimed at producing cobalt-60 and steam for process industry use, and said to be the first reactor project in the world designed specifically as a profit making venture, is in the advanced planning stage at Isotope Products Inc., Buffalo, N. Y.

Location of the reactor is not determined as yet (it has been narrowed down to either the deep South or New England), will depend largely on the contract Isotope can make with a pulp and paper company to use Isotope's steam.

The reactor is designed to produce approximately 1 million curies of cobalt-60 a year, at a price "somewhere near $2 a curie or possibly less," and in excess of 50,000 pounds of steam an hour. The steam is expected to be used by a pulp and paper mill.

The reactor will be a variation of the "boiling water" type, will have excellent safety characteristics, perfectly steady operation, and low operating costs, according to the company. Design of the reactor is being done by General Nuclear Engineering Corp. of Dunedin, Fla. Full operation is expected by the fall of 1958. □



3 MATERIALS are exposed to nitric acid in comparison test of corrosion resistance. From left to right, they are steel, REFRAX® silicon-nitride-bonded silicon carbide refractory, and copper. Only the refractory remains unaffected.

Refractories for outstanding **corrosion resistance**

Wherever the possibility of chemical attack exists, it pays to consider refractories as materials of construction. The picture shows why. In numerous corrosive applications, CARBORUNDUM'S refractories are proving superior to other materials. They resist many highly basic substances as well as acids, acid slags and fluxes.

Typical applications are: linings in controlled atmosphere furnaces, pumps and pump parts handling molten aluminum, nozzles spraying corrosive *and* abrasive liquids, linings in muriatic acid furnaces, retorts for reducing and refining zinc ores, linings for glass tanks, etc.

But seldom is a refractory called upon to provide corrosion resistance alone. It may be required to transmit heat rapidly, resist thermal shock cracking, withstand abrasion, carry heavy loads, retain initial purity . . . whether at low or extremely high temperatures.

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Please send me:

- ☐ Forthcoming issue of Refractories Magazine
- ☐ Bulletin on Properties of Carborundum's Super Refractories
- ☐ Here is a description of my corrosion problem. Can you help me?

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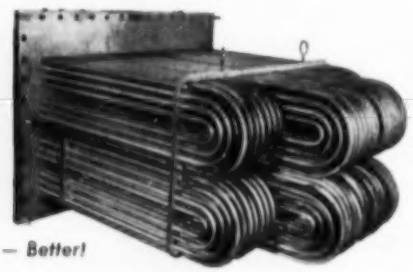
Why your *Paracoil* corrosion-resistant heat exchanger won't "get weak in the knees"

...or at the joints either. Corrosion-resistant materials have a habit of losing their corrosion-resistant properties at critical points if not properly fabricated. But Davis Engineering's skill and experience in metals and alloys insures you Heat Exchange Equipment with constant corrosion-resistant strength... especially at the "knees".

Davis Engineering is prepared to meet all your requirements for heat exchangers and process equipment by designing and fabricating equipment in bronze, copper, Monel, Inconel, carbon and stainless steels, nickel and aluminum.



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INSTITUTIONAL NEWS

The West Coast Section of the Air Pollution Control Association held its First Technical Meeting at the Statler Hotel in Los Angeles on March 25 and 26, 1957. Attendance was more than 300. A full two-day session was devoted to the automobile problem, one full day to incineration, and a half day each to the organic solvents problem and to power-plant emissions. Need for further research on the composition of auto exhaust and the specific relationship of auto exhaust constituents to smog manifestations was clearly brought out during the meeting. Similarly, a need for stepped-up activity on the development of devices for controlling the organic and nitric oxide content of auto exhaust became apparent.

New address of the Air Pollution Foundation after June 1, 1957, will be 2556 Mission Street, San Marino, Calif. □

A new program leading to the degree of master of science in nuclear technology will be offered at the University of Buffalo starting in September, 1957. New courses in nuclear physics, chemistry, and engineering are part of a plan to gear the University's training and research facilities to the demands of the field of nuclear development. The new program will be coordinated with the University's Nuclear Research Center Project. □

The Fourth Annual Symposium of High Vacuum Technology will be held in Boston on Oct. 9, 10, and 11, 1957, at the Hotel Somerset. Authors who would like to submit papers dealing with methods of producing and measuring vacuum, new processes using vacuum, fundamental developments in vacuum technology, or the use of vacuum in research, should contact the Committee on Vacuum Techniques, P.O. Box 1282, Boston 9, Mass. □

The Technical Institute of the University of Dayton will offer a program in chemical technology to begin in September, 1957. Designed to prepare students for technological services in chemical manufacturing plants and processing industries as well as for technician positions in chemical laboratories, the program will lead to an associate degree after two years of study. Specialized courses will include an introduction to industrial chemistry, quantitative analysis, and inorganic, organic, physical, and applied chemistry. □

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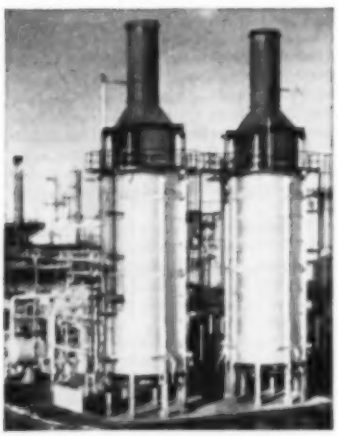

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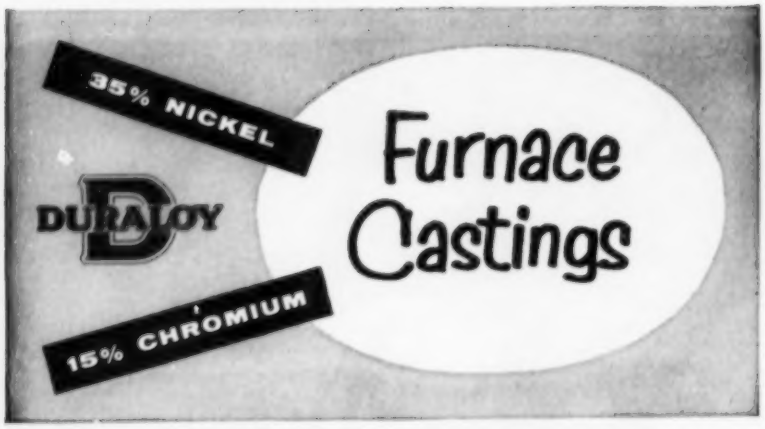

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INSTITUTIONAL NEWS

Mellon Institute will undertake a major expansion of fundamental research activity according to plans recently adopted by the Board of Directors. The decision to reorient the Institute's principal investigational activities toward long-range basic scientific objectives follows a broad assessment of the role of the Institute carried out over a period of several years. □

Standardization—Economy Through Application will be theme of Sixth Annual Meeting of Standards Engineers Society, to be held at Hotel Commodore, New York, September 23, 24, and 25, 1957. □

Chemical engineers will find much interesting and valuable material by authors prominent in their fields in the June issue of the *A.I.Ch.E. Journal*. Contents include:

Separation methods: Froth-frothate Concentration Relations in Foam Fractionation, Separation of Liquids by Thermal Diffusion.

Fluid Flow: Hydraulics of Wetted-wall Columns, Pressure Drop for Flow of Steam-water Mixtures in a Heated Annulus and through Orifices, Dynamics of Liquid Agitation in the Absence of an Air-liquid Interface, Simplified Flow Calculations for Tubes and Parallel Plates, Fluidization and Sedimentation of Spherical Particles.

Heat Transfer: Study of Laminar-flow Heat Transfer in Tubes, Effect of Wall Roughness on Convective Heat Transfer in Commercial Pipes.

Kinetics: Control of Continuous-flow Chemical Reactors (two papers), Rate Studies in Tubular Reactors, Reaction Kinetic Studies: Catalytic Dehydrogenation of Sec-butyl Alcohol to Methyl Ethyl Ketone.

Diffusion and Mass Transfer: Diffusion in Three-component Gas Mixtures, Some Remarks on Longitudinal Mixing or Diffusion in Fixed Beds, Mass Transfer in a Continuous-flow Mixing Vessel, Investigation of Gas Mixing in a Square Duct.

Absorption and Distillation: Performance of Packed Columns: Part 4, Effect of Gas Properties, Temperature, and Pressure on Gas-phase Mass Transfer Coefficients, Densities of Liquid-Acetone—Water Solutions up to Their Normal Boiling Points, Radioisotope Tracer Technique for the Determination of Holdup and Flow Characteristics in Packed Countercurrent Liquid-Liquid Extraction Columns, Adsorption and Stripping-factor Functions for Distillation Calculation by Manual and Digital Computer Methods.

Ion Exchange: Equilibrium in the System Cu^{++}—Na^{+}—Dowex-50, Ion Exclusion Equilibria in the System Glycerol—Sodium Chloride—Water—Dowex-50, Ion Exchange Separation of Gram Quantities of Americum from a Kilogram of Lanthanum.

Thermodynamics: Heats of Mixing, Volumetric and Phase Behavior of the Hydrogen—*n*-hexane System, Phase Behavior of Hydrogen—Light Hydrocarbon Systems, Vapor-Liquid Equilibria of Benzene—*n*-hexane and Benzene—cyclohexane Systems at Pressures above Atmospheric.

Mathematics: Approximate Operational Calculus in Chemical Engineering.

Copies of this significant chemical engineering quarterly are available from the Institute offices at 25 West 45 St., New York City.

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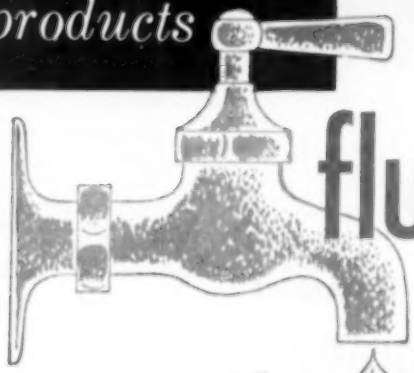

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WATER

Some communities will, some won't . . . adopt fluoridation of drinking water for the purpose of reducing tooth decay. The subject is hotly debated but one thing is certain: wherever fluoridation is adopted a derivative of Sulphur will enter the picture.

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FUTURE MEETINGS

The 8-mile long $50 million Chesapeake Bay Bridge near Baltimore is a connecting link in the growing Atlantic Coast expressway system.

MEETINGS **SYMPOSIA**

■ **BALTIMORE, MD.**

September 15-18, 1957. Lord Baltimore Hotel. See story on page 69.

TECHNICAL PROGRAM CHAIRMAN: R. L. Copson, Mutual Chemical Co. of America, 1348 Block St., Baltimore 31, Maryland.

Adsorption, Dialysis, and Ion Exchange

Intended to furnish basic information for chemical engineers working on mass separation problems.

Jet Propulsion

Emphasis will be on manufacture of chemical fuels. One paper on application to Earth Satellite program.

The Alkali-Chlorine Industry

A management symposium on technological problems, trends, and end uses.

Drying

Aspects of industrial drying, including spray drying techniques.

Low Temperature Processing

The second symposium on this subject following an introductory session at the last Boston meeting.

Direct Operating Labor Costs

Featuring an industrial engineering approach to estimation of labor costs.

Air Plant Safety

A panel discussion with a planned agenda.

Ammonia Plant Safety

A panel discussion with a planned agenda.

■ **STATE COLLEGE, PA.**

August 11-14, 1957. Pennsylvania State University.

First National Conference on Heat Transfer. Sponsors: A.I.Ch.E. A.S.M.E., & College of Eng. & Arch., Penn State Univ. Purpose is to provide a forum and an opportunity to exchange ideas and data on the industrial applications of heat transfer.

A.I.Ch.E. program chairman is James N. Addoms, Atlas Powder Co., Wilmington 2, Del.

(Continued on page 90)

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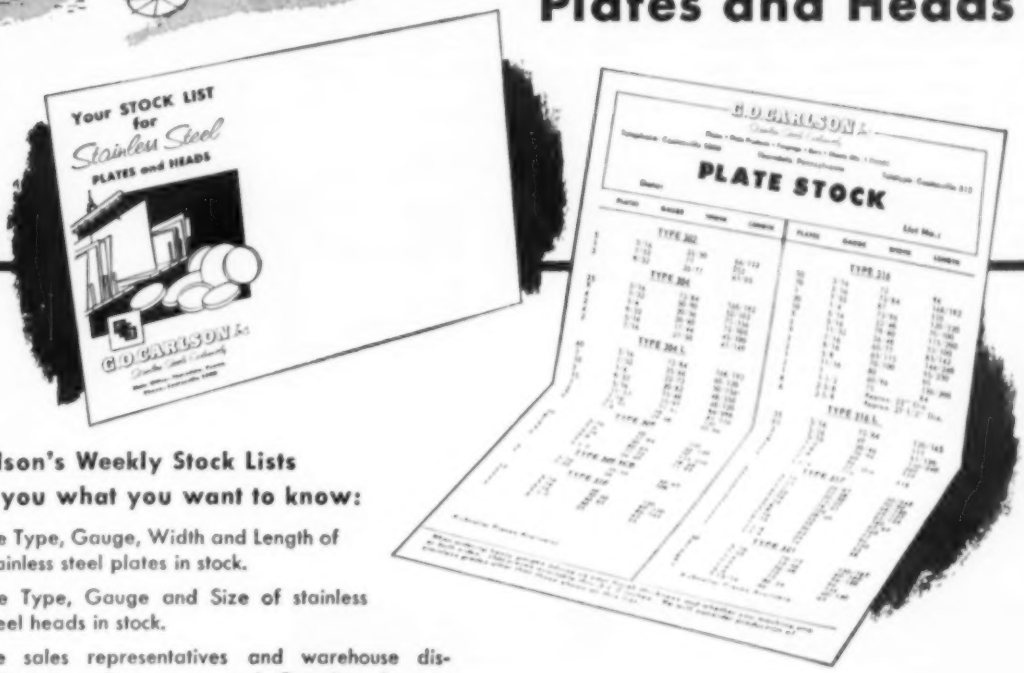

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- the Type, Gauge, Width and Length of stainless steel plates in stock.
- the Type, Gauge and Size of stainless steel heads in stock.
- the sales representatives and warehouse distributors in this country and Canada who are ready to serve you.

YOU can save time by checking these weekly stock lists. Here is an up-to-the-minute report on our large, diversified stock of stainless steel plates and heads that have been produced especially for chemical industry applications.

Carlson plates in Types 304-L, 316-L and 317-L are more and more in demand. Substantial stocks of these extra-low-carbon grades, along with other chromium-nickel Types 302, 304, 309, 309-S, 310, 316, 317, 321, 347 and 348 are available. Chromium grades 405, 410, 430 and 502-½% Mo are always in stock. Two precipitation-hardening grades, Types 17-4 PH* and 17-7 PH*—new plate grades that combine ease of fabrication, hardenability, high strength and corrosion resistance—are now in production and limited stocks are carried. To complete the story, stainless steel heads in Types 304, 304-L, 316 and 316-L are also stocked and can be shipped in a few days.

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ENGINEERS REJECT COLLECTIVE BARGAINING AT MINNEAPOLIS-HONEYWELL

In a nationally important "test case," engineers at Minneapolis-Honeywell overwhelmingly rejected unionization by both the United Auto Workers (CIO-AFL) and the Engineers and Scientists of America.

Engineers also rejected grouping with technicians—big surprise came when technicians voted against unions.

In one of the first major tests of unionization among engineers, Minneapolis-Honeywell engineers voted in May to decertify from Federation of Honeywell Engineers, the collective bargaining unit that had represented them for over ten years. Involved in the complex battle were UAW, ESA, the company, and an organized "decertification" group of non-union engineers.

The vote: UAW—314; ESA—197; No union—896. And for the technicians: UAW—254; ESA—62; No union—404.

The national significance of this election is obvious. Hopewell engineers had been represented by the Federation for ten years, and the Federation was a founding member of ESA. (ESA's president Joe Amann is a Honeywell engineer on leave from the company.) The company made an all-out fight against the union. UAW made no secret of its high interest, sent its top men including president Reuther. At its recent Atlantic City Convention UAW served notice of its aims to organize white collar and professional employees, Honeywell was to be an important opening gun.

What Happened—The Engineers' Story

With so much conflicting interest on a national scale, *CEP* sent its reporter to get the "grass roots" story from the engineers themselves.

Three leaders of the "decertification" movement, never members of the local Federation, are John Ludwig, senior research engineer; William Carlson, senior development engineer; and Marlowe Iverson, development engineer. *CEP* asked Ludwig, how did this happen?

Ludwig's answer—"Collective bargaining tactics, methods, and viewpoint, as exemplified by UAW, are not wanted by engineers and scientists. It is not the way we want to deal with our employers."

It all began, Ludwig explained, ten years ago when three groups of engineers with divergent opinions formed the local Federation of Honeywell Engineers (then called the Minneapolis Federation of Honeywell Engineers). The first group were labor unionists in the traditional sense, had CIO affiliation ready to go in 1945, would have taken the engineers into the trade union movement. The second group were those with many complaints against the company who wanted some organization to speak for them but did not want full-fledged trade unionism. The third group were esentially anti-union but under the terms of the then-in-force Wagner Act, which did not protect professionals from inclusion in production unions, felt they had to organize a local federation to prevent being swept into a CIO union. (Taft-Hartley has changed this, protects professionals.)

At first the Federation was academic, did little. Soon it helped form ESA and the "militant" unionists gained more control. In 1955 there was a one-week strike that failed. After the strike, UAW came in. In the spring of 1956 the Federation took a vote to change from ESA to UAW affiliation but failed to get the ⅔ majority required. Then in February of this year the Federation voted (579—116) to disaffiliate with ESA and join UAW.

The "decertifiers" organized a steering committee, sent out cards asking for decertification, got back more than the legally required 30% of the "bargaining unit" (the bargaining unit is *all* Honeywell Engineers not just members of the Federation), petitioned for a decertification election. The company also petitioned for an election on the grounds of not knowing whom they should bargain with.

The election was ordered for May 8 and a lot of campaigning began on all sides. UAW charged at first that the company and the decertifiers were in collusion but soon dropped this charge. ESA campaigned vigorously against UAW and "no union"—"a vote for no union is a vote for UAW."

Over 95% of the engineers voted. The result was a strong repudiation of the collective bargaining concept.

Today, all sides are evaluating. There is a one-year moratorium on another election, UAW is not giving up, is studying its defeat. The Honeywell engineers "don't know what we'll do from here. Some of us are looking into the advantages of a 'sounding board' organization, but we have no definite plans."

(*Continued on page 90*)

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1930's Croll-Reynolds focuses on the need for high vacuum in the growing chemical field—gives special attention to design of 4 and 5 stage EVACTORS, and also to the application of steam jet refrigeration equipment.

1940's Croll-Reynolds directs activity toward war effort, supplies a great number of EVACTORS for shipboard use, special units for the atomic program, and equipment for manufacturing new types of explosives and chemicals. **In the late 1940's,** Croll-Reynolds develops and supplies vacuum equipment for vacuum cooling of fresh vegetables.

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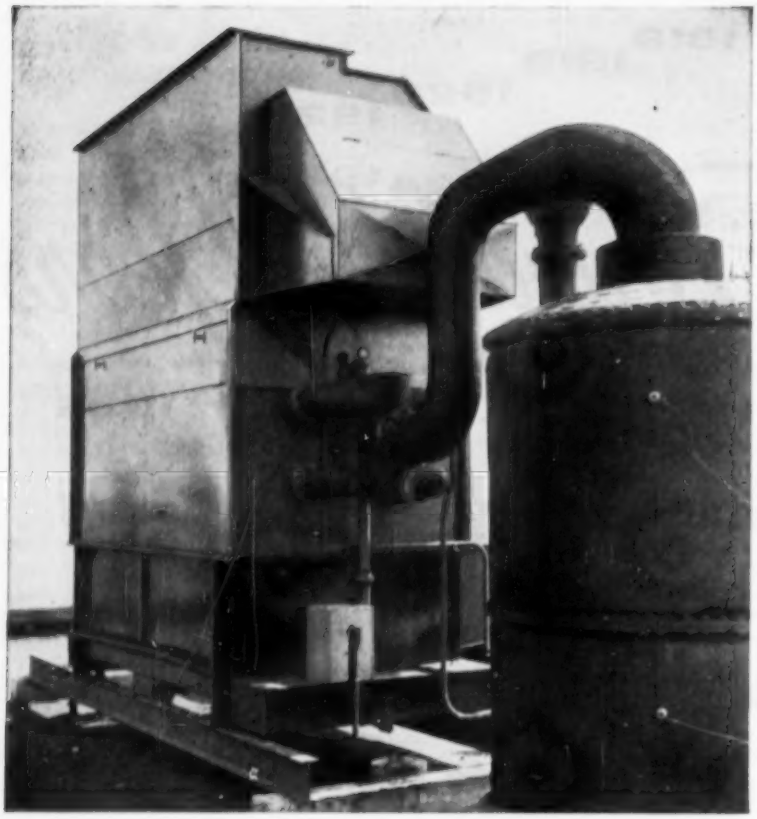

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COLLECTIVE BARGAINING

(Continued from page 88)

Why did the engineers turn away from an organization that had represented them for ten years? Ludwig says, "Well, there's the basic feeling that we don't want trade-union type representation when we deal with our company, and the more militant group had begun to take over the Federation and head toward CIO-AFL. Perhaps most important was the simple fact that there were legitimate gripes in the beginning against the company but company policy has improved greatly over the last years." Other engineers said simply, "we had a change of viewpoint after the union had been with us a while." And, "we organized our opposition!"

FUTURE MEETINGS

(Continued from page 86)

MEETINGS **SYMPOSIA**

■ **BOULDER, COL.**

August 19-21, 1957. National Bureau of Standards offices. Cryogenic Engineering Conference.

For information contact K. D. Timmerhaus, Dept. of Chemical Engineering, Univ. of Col., Boulder, Col.

Program includes: **Cryogenic Process**—liquefaction cycles, purification of gases, distillation, fluid flow, catalysis. **Cryogenic Equipment**—dewars, pumps, expansion engines, heat exchangers. **Cryogenic Properties**—mechanical, electrical, thermal, vacuum insulation, powder insulation. **Cryogenic Applications**—expansion engines and turbines, cryogenic fuels and oxidants, bubble chambers.

■ **CLEVELAND, OHIO**

September 7-13, 1957, Cleveland Auditorium. Annual Instrument-Automation Conference & Exhibit of the Instrument Society of America. Conference theme will be "Instrumentation for Systems Control." Educational aspects will be emphasized. A.I.Ch.E. members are invited to register at same rate as ISA members.

■ **ANNUAL—CHICAGO, ILL.**

December 8-11, 1957. Conrad Hilton Hotel. TECHNICAL PROGRAM CHAIRMAN: Henry F. Nolting, Standard Oil Co., 2400 New York Ave., Whiting, Ind. Those interested in submitting papers for consideration should address themselves directly to the chairman of the appropriate session.

Fluidization of Solids

CHAIRMAN: E. R. Gilliland, Chem. Eng. Dept., M.I.T., 77 Massachusetts Ave., Cambridge 39, Mass.

Effective Cost Control in Process Operations

CHAIRMAN: C. W. Nofsinger, The C. W. Nofsinger Co., 906 Grand Ave., Kansas City 6, Mo.

Evaluation of Projects from the Original Idea to the Investment Stage

CHAIRMAN: C. W. Nofsinger (see above).

(Continued on page 92)

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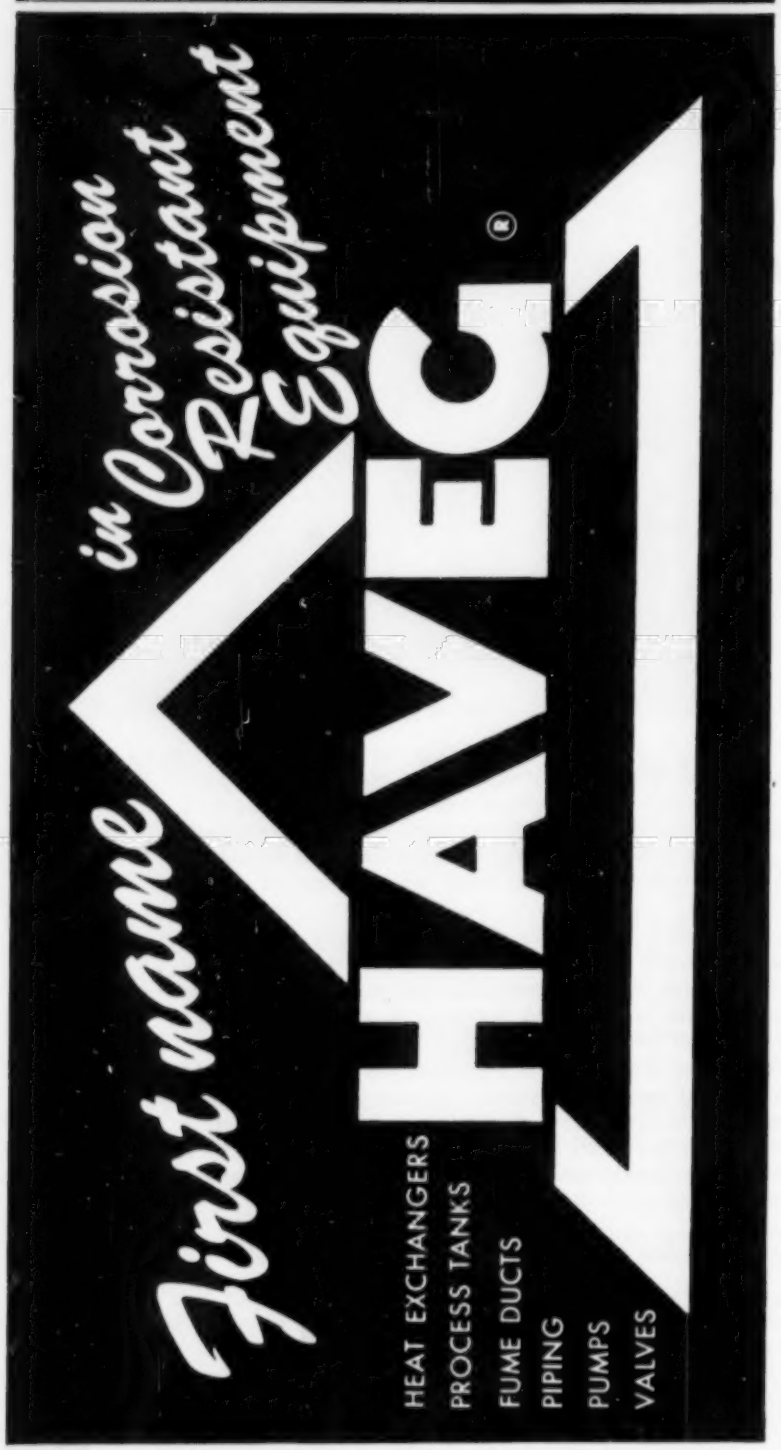

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FUTURE MEETINGS

(Continued from page 90)

MEETINGS **SYMPOSIA**

Chemical Engineering Abroad

CHAIRMAN: Shelby Miller, Chem. Eng. Dept., University of Rochester, River Campus Station, Rochester 20, N. Y.

Corrosion Resistant Alloy Materials of Construction

CHAIRMAN: G. Fred Ours, Carbide and Carbon, Charleston, W. Va.

Laboratory and Pilot Plant Techniques

CHAIRMAN: G. W. Blum, The Goodyear Tire & Rubber Co., 1485 E. Archwood Ave., Akron 16, Ohio.

Production of Heavy Water

CHAIRMAN: W. Bebbington, du Pont Savannah River Plant, Aiken, South Carolina.

Radiation Processing

CHAIRMAN: J. J. Martin, Dept. of Chem. Eng., Univ. of Michigan, Ann Arbor, Michigan.

Nuclear Process-Heat and Radiation Source Reactor Systems for the Chemical and Metallurgical Industries

CHAIRMAN: B. W. Gamson, Borg-Warner Corporation, Des Plaines, Illinois.

Extractive Metallurgy

CHAIRMAN: B. W. Gamson (see address above).

Selling a Technical Program

CHAIRMAN: W. L. Bulkley, Standard Oil Company (Ind.), Whiting, Indiana.

Shock Waves in Process Equipment

CHAIRMAN: Stuart Churchill, Dept. of Chem. Eng., Univ. of Michigan, Ann Arbor, Michigan.

Impact of Computers on the Practices of Chemical Engineering

CHAIRMAN: Leon Cooper, Monsanto Chemical Company, St. Louis, Missouri.

The Separation of Materials in Biological Processes

CHAIRMAN: Elmer Gaden, Dept. of Chem. Eng., Columbia University, New York City.

Chemicals Recovery in the Paper Industry

CHAIRMAN: R. P. Whitney, Inst. of Paper Chemistry, Appleton, Wisconsin.

Process Application of Reactors

CHAIRMAN: J. J. Martin, Univ. of Michigan, Dept. of Eng., Ann Arbor, Michigan.

■ 1958 MEETINGS

• Montreal, Canada, April 20-23, 1958. Sheraton-Royal Hotel. Joint A.I.Ch.E.-C.I.C. Conference. A.I.Ch.E. CHAIRMAN: Kenneth Beatty, North Carolina State College, Raleigh, N. C. CO-CHAIRMAN: W. H. Gauvin, McGill University, Montreal.

• Philadelphia, Pa. June 22-27, 1958. Bellevue-Stratford Hotel. A.I.Ch.E. Fiftieth Anniversary Meeting. CHAIRMAN: Roy Kinckiner, DuPont, Wilmington, Del. See further details of meeting and program listed below.

• August 18-21, 1958. A.I.Ch.E.-A.S.M.E. Heat Transfer Conference. CHAIRMAN: A. S. Foust, Dept. of Chem. Eng., Lehigh University, Bethlehem, Pa.

(Continued on page 94)

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Quick facts about the services and equipment available to help you reduce corrosion and processing costs.

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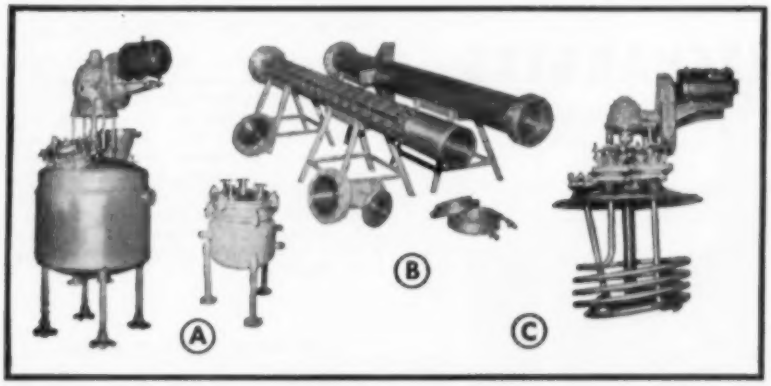


A. Pfaudler titanium reaction kettles for high-temperature processing.
B. Pfaudler packed floating head titanium heat exchanger.
C. Pfaudler titanium loop coil for use in titanium reactor.

When should you use titanium process equipment?

Titanium, a relatively new material of construction, shows great promise in reducing corrosion costs under severe chemical conditions.

As corrosioneers, Pfaudler has studied its characteristics, developed welding techniques, designed and built quite a range of titanium process equipment. Some are shown above and others are being fabricated now.

Because production costs of titanium have been greatly decreased, titanium should now be considered as a material of construction wherever it is economically feasible to do so. It has superior resistance to nitric acid solutions at high temperatures, chlorinated organics and inorganic chloride solutions, and shows excellent resistance to mixtures of sulphuric and nitric acids and also to aqua regia.

There are also other materials which provide excellent chemical resistance, among which is Pfaudler glassed steel. Each case should be considered on its own merits.

Our main point is this: When you are up against any kind of a corrosion problem, Pfaudler is ready and anxious to give you the benefit of its 73 years of experience in designing and fabricating equipment that will do the best job at *the lowest over-all service cost*. If titanium is indicated, you can rely on Pfaudler know-how to do just that. Your inquiries are welcomed.

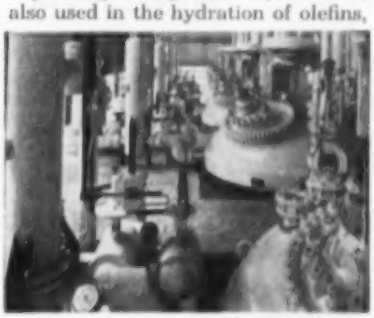
Copper and copper alloy equipment . . . For services involving acid solutions of low oxidizing capacity, copper and copper alloys may be the best answer to your problem. Pfaudler's long experience in building copper vessels and heat exchangers assures you of top-quality engineering and workmanship. You will also find Pfaudler prices competitive. Let us quote on your requirements for equipment of this type.

Glassed steel for the petroleum industry

The petroleum industry, like chemical processing, finds in glassed steel equipment a material of construction which is proving most economical in the battle against corrosion.

Great improvement in the resistivity of Pfaudler glass and its application to many different types of open hearth steel designs, are mainly responsible for this trend. Pfaudler glass, now resistant to all acids (except hydrofluoric) and to alkaline solutions to pH 12 at 212° F., provides about as much flexibility as you can find in any one material of construction.

Used in the form of reactors, columns, settlers, mixers, storage tanks, pipe, fittings and valves, Pfaudler equipment is giving excellent service for reactions involving hydrochloric acid, chlorinated solvents, pesticides, vapor degreasing solvents, etc. It is also used in the hydration of olefins,



to prevent corrosion by sulphuric acid, in certain phases of producing cumene-derived phenol and by-product acetone in polyester resins and synthetic fibres.

Installations of Pfaudler glassed steel polymerizers are so numerous that standardized designs have been developed. Glassed steel can be cleaned quickly after each run; a build-up of product within the vessel is easily prevented.

In petroleum refining operations, corrosion during crude distillation has been minimized. Glass helps to prevent passage of hydrogen to the steel surface, eliminating atomic hydrogen attack. There are other applications too numerous to include here. May we send you more information?

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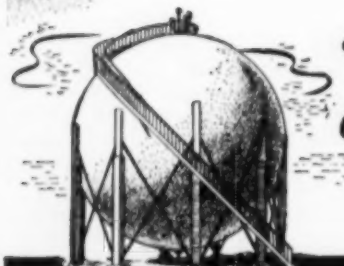
* *Aerofin makes extended heat surface exclusively — not as a by-product, not as a side-line.*



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FUTURE MEETINGS

(Continued from page 92)

• Salt Lake City, Utah, September 21-24, 1958. CHAIRMAN: E. B. Christiansen, Dept. of Chem. Eng., Bldg. 437, Univ. of Utah, Salt Lake City. **Air Pollution**—CHAIRMAN: W. L. Faith, Air Pollution Foundation, 704 S. Spring St., Los Angeles 14, California. **What's New in Liquid Metals Technology**—CHAIRMAN: Marshall Sittig, American Lithium Institute, Inc., P. O. Box 549, Princeton, N. J.

• Cincinnati, Ohio, December 7-19, 1958. Netherland Plaza Hotel. A.I.Ch.E. Annual Meeting. TECHNICAL PROGRAM CHAIRMAN: A. C. Brown, Emery Industries, Inc., June & Long Streets, Ivorydale, Ohio. **Water Pollution**—chairman to be named. **Distillation**—CHAIRMAN: W. C. Schreiner, M. W. Kellogg Co., 711 Third Ave., New York 17, N. Y. **High-Speed and Time-Lapse Photography in Chemical Engineering**—CHAIRMAN: J. W. Westwater, William Albert Noyes Laboratory, Univ. of Illinois, Urbana, Ill.

FIFTIETH ANNIVERSARY MEETING

■ Philadelphia, Pa. June 22-27, 1958. Bellevue-Stratford Hotel. A.I.Ch.E. 50th Anniversary Meeting. CHAIRMAN: Roy Kinckiner, DuPont, Wilmington, Del. Theme for program is: **A Look to the Future.** All symposia and papers are being planned in accordance with this theme.

To permit prepublication, which is desired by the Committee, **deadline for submission of papers to the Technical Program Committee is June 30, 1957.** Where prepublication is impracticable, the deadline is tentatively fixed at November 30, 1957.

Comments and suggestions are invited. Proposals of papers should be directed to symposium chairman, with carbon copy to Roy A. Kinckiner.

LOCAL SECTION MEETING

■ **PETERSBURG, VA.**

October, 1957. One-day meeting on Industrial Pollution Control and Heat Transfer sponsored by Central Virginia Section, A.I.Ch.E. Suggestions for papers should be sent to W. H. Wright, 1020 Johnson Ave., Petersburg, Virginia.

UNSCHEDULED SYMPOSIA

Proposed, but unscheduled, symposia of the Institute may be found listed in April *CEP*, page 114. Correspondence on proposed papers is invited by the program chairmen.

AUTHOR INFORMATION

Submitting Papers

Procedure to be followed is, in brief:

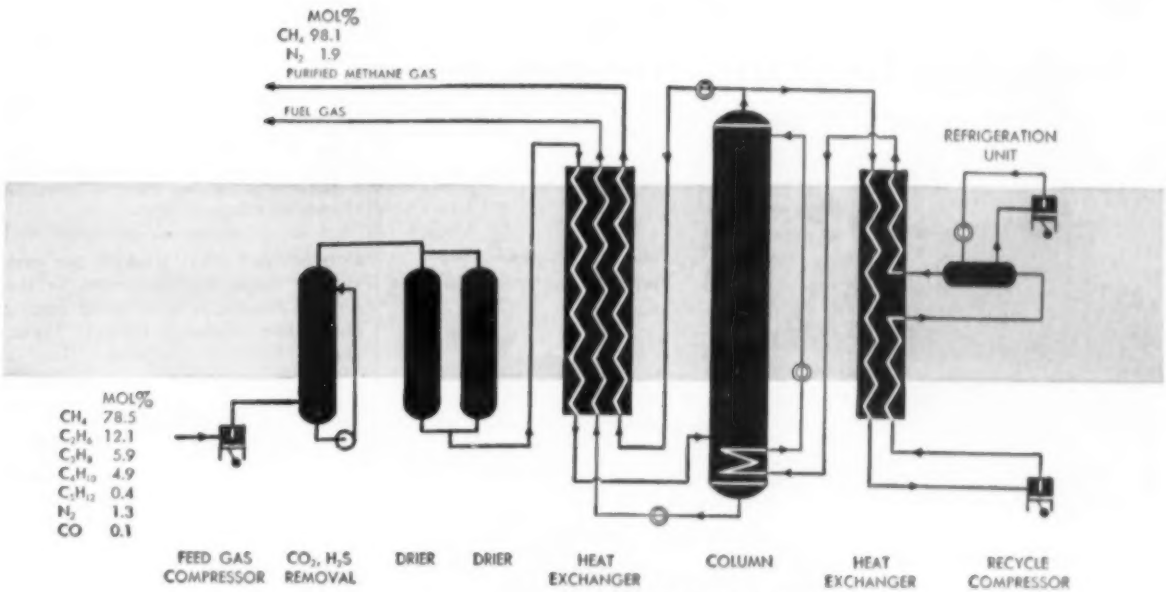
1—Obtain four copies of "Proposal to present a paper before the A.I.Ch.E.," plus one copy of "Guide to Authors" from Secretary, A.I.Ch.E., 25 West 45th St., New York 36, N. Y.

2—Send one copy of completed form to Technical Program Chairman for meeting selected from above list.

(Continued on page 96)

practical approach to

METHANE PURIFICATION



Methane gas purification unit

In the production of chlorinated methane compounds and other chemicals based upon methane, the methane processed must be of ultra high purity. Air Products low-temperature processing plants—accepted as the most economical and practical approach—produce methane containing less than 100 p.p.m. of other hydrocarbons.

Air Products methane purification plants feature many cost-saving and special processing advantages:

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- valuable by-products—LPG, other heavy hydrocarbons, nitrogen.
- automatic control—requiring a minimum of labor.
- low power consumption.
- factory-assembled plants—assuring minimum installation expense.

Many chemical plants are already using Air Products low-temperature equipment. In addition to the production of ultra high-purity methane, Air Products units are being used for the production of oxygen, nitrogen, argon and hydrogen . . . as well as the processing of natural gas, carbon monoxide, deuterium, fluorine and helium.

Here at Air Products, we design, manufacture, erect and operate . . . package, tonnage and custom-built industrial gas separation, liquefaction and purification systems. No matter what your requirements, Air Products will find a way for you to acquire or lease low-temperature equipment on mutually convenient and beneficial terms. Your inquiry is invited. Air Products, Incorporated, P. O. Box 538, Allentown, Pa.

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photo on left showing two large phosphoric acid tanks.

photo on right showing one of two 50% sulfuric acid tanks.

The above photographs picture a recent Atlas installation at the U.S. Industrial Chemicals Co., Div. of National Distillers Products Corp., at Tuscola, Illinois. This type of construction is typical of the "Plant-Wide" corrosion protection service that Atlas offers to the Chemical Industry.

The above installation consisted of two tanks for 50% hot sulfuric acid and two tanks for phosphoric acid. All work was done by Atlas crews at the job site.

Yes, there is a big plus beyond the price when you specify Atlas, only then will you get a completely integrated construction service, one that will accept full and sole responsibility for your job and will guarantee every aspect of it. This unique service is available to your industry, anywhere in the world, for new plant construction, expansion or maintenance work. Whatever the requirements, Atlas can and will do it right and on time.

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MERTZTOWN, PENNSYLVANIA

FUTURE MEETINGS

(*Continued from page 94*)

AUTHOR INFORMATION

3—Send another copy to Mr. E. R. Smoley, The Lummus Co., 385 Madison Ave., New York 17, N. Y. (Asst. Program Comm. chairman).

4—Send third copy to Editor, Chemical Engineering Progress, 25 West 45th St., New York 36, N. Y. Paper will automatically be considered for possible publication in A.I.Ch.E. Journal.

5—If desired to present paper in a selected symposium, send fourth copy to chairman of the symposium.

6—Prepare five copies of manuscript. Send one copy each to Symposium chairman, Technical Program chairman, or both copies to former if no symposium is involved. Other three copies should be sent to Editor, C.E.P. Presentation at meeting offers no guarantee of acceptance for publication.

Polymerized ethyl silicate, not previously made by Monsanto in the United States, is now being turned out by the company's Everett, Mass., plant. Formerly imported from a Monsanto subsidiary in England, the domestic product, in addition to its use in the investment casting industry, is being investigated for application in other processing fields. The polymer appears to have promise as a binder for high-temperature refractories, in the treatment of graphite carbon molds, in a refractory wash for furnace linings, for application to stone or ceramic surfaces to retard weathering, and as a binder in powder metallurgy. □

Project Development was the theme of the Eighth Industry-sponsored School to be held in the Southwest (May 24, 1957). Organized and sponsored by the Lummus Co., the school was attended by teachers of chemical engineering from colleges and universities in Texas, Arkansas, Louisiana, Oklahoma, and New Mexico. Specialists from the Lummus Co. discussed the whole process of project development "from inquiry to acceptance by the customer." □

A Royal Charter has been granted by the Queen to the Institution of Chemical Engineers (London, England). In contrast to the early development of chemical engineering as a separate and distinct profession in the United States, where the first course in the subject began at M.I.T. in 1888, recognition of the chemical engineer has come more slowly in Great Britain. The Institution of Chemical Engineers, for instance, was not founded until 1922 after the experience of World War I had convinced British chemical engineers of the utility and efficiency of the American approach to the subject based on the concept of "unit operations" developed chiefly by W. K. Lewis of M.I.T. □

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Our widely-experienced technical and manufacturing staff, including design, process, project and mechanical engineers, backed by half a century of "know-how," is at your service to assist you in applying low-temperature technology to your particular requirements. We shall be glad to consult with you regarding cost analyses and technical aspects in the design and manufacture of complete plants or components "tailored" to your needs.

Air Liquide low-temperature air separation unit for producing high-purity nitrogen.

Similar A.L. unit for recovering hydrogen from coke-oven gas.

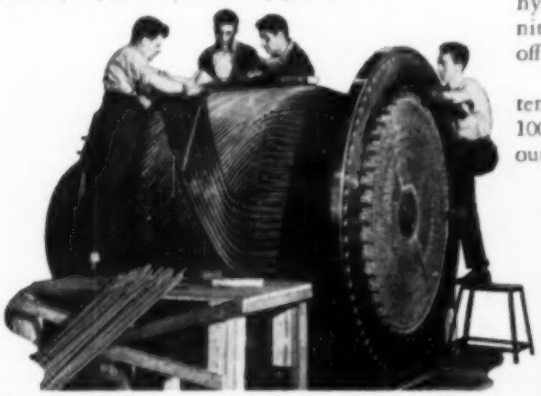
Ketona Chemical, at Birmingham, Alabama, has successfully inaugurated the first ammonia plant in this country designed exclusively around coke-oven gas as a source of hydrogen. The low-temperature gas separation units used at Ketona were designed and built by American Air Liquide.

A portion of Air Liquide's Engineering and Construction Division fabricating plant at Montreal, Que. Under fabrication here are numerous all-welded stainless steel shells to house component exchangers, vaporizers, rectification columns, etc., of the liquefaction equipment.

Low-temperature separation processes, for recovering atmospheric and hydrocarbon gases in tonnage quantities, are being used on a rapidly increasing scale in the United States.

Once confined to the separation of oxygen, nitrogen and the rare gases of the atmosphere, the low-temperature liquefaction process of separation is today successfully producing high-purity hydrogen, pure carbon monoxide, methane, ethylene, propane and nitrogen, from such gaseous mixtures as: natural gas, refinery off-gases and coke-oven gas.

During the past 50 years, Air Liquide (a pioneer in the low-temperature gas separation field) has designed and built more than 1000 hydrocarbon and air-separation plants for industries throughout the world. In the United States it is a leader in this field.



The fabrication of an Air Liquide wound tube-type exchanger can involve over 10 miles of intimately interwoven copper tubing to provide the necessary cooling surfaces in this specialized low-temperature equipment.

Centre of control panel for a large-tonnage oxygen plant includes a flow sheet for the operator's guidance. Once put "on stream", operation of Air Liquide low-temperature plants is almost entirely automatic.

L'Air Liquide, its affiliates and subsidiaries have offices and plants throughout the world: Algeria, Argentina, Belgium, Brazil, Cameroon, Canada, China, Egypt and Sudan, France, French Congo, French West Africa, Gold Coast, Great Britain, Greece, Indochina, Italy, Ivory Coast, Japan, Lebanon, Luxemburg, Madagascar, Malay States, Morocco, Netherlands, Paraguay, Portugal, Siam, South Africa, South-East Asia, Spain, Sweden, Syria, Tunisia, and the United States of America.

ABSORBERS PUT TO THE TEST

What has been done to standardize testing procedures for absorption equipment in the chemical processing industry? An authoritative practical guide to designers, fabricators, and users is now available, based on testing at design feed conditions and providing for variations if necessary.

Until recently, chemical processing equipment was usually tested only according to the experience and standards of individual engineering or operating companies. Little effort was made to arrange for exchange of information between companies; in fact, testing techniques were often closely guarded as a branch of industrial "know-how."

Equipment designers and fabricators were often severely handicapped because their equipment was subject to tests based on a great variety of different procedures. They could never be entirely sure what performance characteristics their equipment would be expected to meet nor under what conditions. In addition, during actual acceptance tests under purchase contracts, it is common that initial and terminal design operating conditions cannot be met exactly. Until the recent appearance of the A.I.Ch.E. Test Procedures for Heat Exchangers,* no standard, generally accepted method was available for setting up alternative test conditions the results of which could be extrapolated and interpreted to the mutual satisfaction of both equipment vendors and purchasers. Now, with the appearance of a new Test Procedure, the field has been extended to absorbers.

* Under the sponsorship of the Equipment Testing Procedures Committee of A.I.Ch.E., work has been going forward since 1944 to "coordinate testing procedures for the performance of chemical processing equipment."

Three testing procedures have now been issued officially and are available in pamphlet form from the New York offices of the A.I.Ch.E. These are: Heat Exchangers, Parts I and II, plus the one on Absorbers which is the subject of this article.

Procedures presently in preparation include: Corrosion Testing, Distillation Equipment, Dryers, Evaporators, Measurements, Mixers, and Pumps.

Work in the absorber field has been carried out under the direction of the A.I.Ch.E. Sub-Committee on Absorbers, E. G. Scheibel, chairman, W. M. Gaylord, C. H. Gilmour, H. Hipkin, C. J. Kramis, and E. J. Lyons.

The Absorber Testing Procedure, in common with the rest of the series, is intended to be a practical guide rather than a theoretical treatise. Methods and techniques described in the text are completely understandable even to non-chemical engineers such as chemical plant operators. Mathematical formulas have been kept to a strict maximum. Derivations, etc., necessary to a complete theoretical understanding of the subject are referred to in the bibliography.

Scope of the procedure is limited to absorption of gases in liquids and does not include absorption of gases on solids. It covers any equipment in which the prime purpose is to effect a transfer of material from a gas phase to a liquid phase by direct contact between the phases. The gas phase may contain nonabsorbable gases in any concentration. The procedure also includes absorption in which chemical reaction takes place.

Evaluation of Results for Acceptance Tests

All possible efforts should be made to conduct the acceptance test for an absorber at the design conditions. A comparison of the predicted and observed compositions and temperatures of the product streams will immediately indicate whether the absorber is performing according to the specifications within the limits of accuracy of the experimental data. If the absorber cannot be supplied with the design feed conditions, the extrapolation of the test data to the design condition will have to be decided by agreement between the parties involved.

If performance data are available on a similar unit or if a correlation of the performance has been developed on pilot plant or other similarly designed equipment, extrapolation may be on the basis of these correlations.

The procedure goes on to a discussion of extrapolation based on equipment performance under specified conditions. If other performance data are unavailable, and a general method of correlation for the performance of the particular equipment cannot be established, the test run should be made on the absorber under an arbitrary set of conditions to give data relative to the original design conditions. Test methods are given based on a deviation of one of the variables from the design values. They can also serve as a basis for selection of a representative set of conditions when more than one variable differs from the original design basis.

All factors necessary to a significant analysis of absorber performance are correlated and brought together into a

(*Continued on page* 100)

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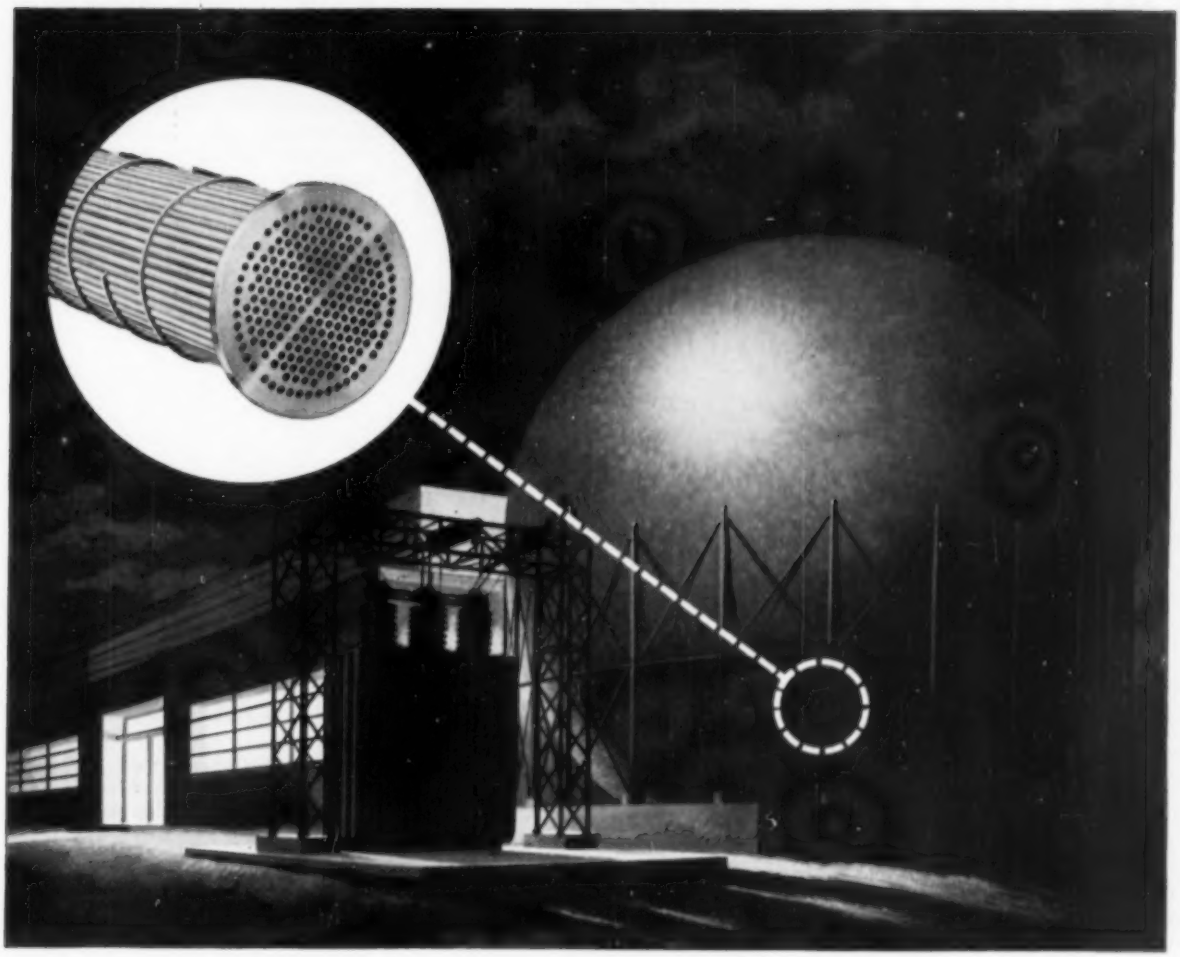

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When the count starts rising in a nuclear pile and the reactor goes critical, the heat exchanger begins its vital function. Reactor heat exchangers require tubing of the highest quality.

This tubing must offer rapid and efficient heat transfer. It must be bright and clean, with extremely smooth ID and OD surfaces for uninterrupted fluid flow. Walls must be uniform throughout—no heavy sections to slow down heat transfer, no thin spots where scaling or corrosion might gain a foothold. Ductility is also important for fabrication ease. Excellent weldability is a prime requirement.

Superior has been supplying high quality tubing in a wide variety of analyses and sizes to heat exchanger manufacturers for many years. We produce to the most exacting tolerances and specifications. Get more information and free literature today on Superior tubing for atomic power. Write Superior Tube Company, 2011 Germantown Ave., Norristown, Pa.

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Actual experience, in hundreds of cases, has proven to the satisfaction of production officials that it is far more economical to cover the cloth or other filter medium with E-D filter paper and then, when the press needs redressing, to simply peel off the paper, discard it, and replace with a clean E-D filter paper cover. Substantial savings in press running time are made.

E-D filter paper holds up solid particles to such a degree that there is often little need for recirculating the slurry to obtain an adequate cake deposit for clear filtration at the start of a cycle.

Moreover, the E-D filter paper protects the filter medium from slimy fines, thus prolonging its useful life, saving additional money on media expenditures. The cost of E-D filter paper is so little, in comparison with the cost of other filter media, that these savings are important.

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Because of its fine porosity and unique uniformity of furnish, grade #953—as well as the many other grades of E-D filter paper—obtains exceptional clarity of filtrate. Many degrees of rapidity and porosity are available in the more than 50 regular grades manufactured by The Eaton-Dikeman Company. Special grades are also made to meet individual requirements.

Free Samples Available

Actual tests made at the user's plant furnish convincing proof of the many advantages that are possible. Simply write for E-D's Filtration Analysis Report. When the necessary facts are supplied, you will receive several recommended grades, cut to your own size and specifications, at no charge. Make the necessary test runs and you will soon be able to determine the benefits for yourself. There is no charge or obligation for this service.

Write to Thomas H. Logan, Jr., care of The Eaton-Dikeman Company, Filtertown, Mount Holly Springs, Pennsylvania for prompt attention.

This company is the only company in America that is exclusively engaged in the manufacture of filter paper for science and industry. Authorized representatives and dealers are located in every section to provide service and helpful information on all problems relating to liquid filtration.

ABSORBERS

(*Continued from page 98*)

coherent standard system of nomenclature. A complete list of necessary measurements is given along with practical methods for taking them under actual plant conditions. Application of the test data is usually only a matter of substituting the values obtained into the simplified basic formulas given in the procedure. Sampling and analysis techniques are given thorough treatment.

Start-up and Test Procedure

Very little material has hitherto appeared in the literature concerning the actual techniques used in starting up equipment for performance or acceptance tests. Here, for the first time, are explained methods which up to now have been the exclusive property of the operating departments of certain large engineering and manufacturing companies. Of particular importance is the question "When does one reach the steady state?" The interpretation of the steady state and the recommended sampling schedules set forth in the procedure are the results of rigorous mathematical calculation and are believed to be of paramount importance and practical utility. Of equal importance, perhaps, is the relationship established between the material balance and the approach to the steady state.

Heat and material balances can be considered as a measure of the reliability of the data and as proof of the attainment of the steady state. Statistical criteria in this respect are given in the procedure.

While a rigorous theoretical basis for correlating the performance data of absorbers has not yet been developed, several empirical methods have gained prominence in the field. These methods are described in the text of the procedure along with the appropriate literature references.

Comment Invited

It is not considered that this Absorber Testing Procedure as published is necessarily in final or definitive form. Comment from users is invited and provisions have been made for periodic review and revision. In the words of Scheibel, chairman of the A.I.Ch.E. Sub-Committee on Absorbers, "We hope that this publication will stimulate discussion in the industry, bring out new ideas and techniques, and serve as a basis for argument."

Next Month: New Test Procedure on Condensers.

News of the Field
FROM LOCAL SECTIONS

PROFESSIONAL PROBLEMS, ENGINEERING ECONOMICS, CHEMICAL TRANSPORTATION ARE AMONG MAJOR SUBJECTS AT LOCAL SECTION MEETINGS

When a young chemical engineer comes from college to industry he is expected to have depth of knowledge rather than breadth of knowledge. This was one of the major points made by A. Hanchett, Solvay Process Division (Allied), when he spoke to the April meeting of the **Maryland Section** (*P. Messina*). To the senior chemical engineering students from Johns Hopkins, who were guests at the meeting, Hanchett emphasized that it is detailed knowledge of fundamentals that a chemical company wants rather than a wide acquaintance with the field. The three basic requirements which management seeks are: 1) Technical knowledge and training; 2) Intelligence and judgment; 3) Personality and character.

At the annual students' night meeting of the **Rhode Island Section** (*J. L. Campanella*) held in April, A.I.Ch.E. president J. H. Rushton spoke to the members and prospective members about the Institute and its objectives. The Institute, Rushton pointed out, is concerned with the individual and performs a vital function by providing him with technical material pertinent to his work. It also encourages and promotes contacts among men doing similar work which can result in the generation of new ideas, new methods. In essence, Rushton concluded, the Institute is one major way a chemical engineer's professional standards are developed and recognized.

At the same **Rhode Island** meeting, Ladislav Dolansky, Northeastern

(*Continued on page* 102)

The second Annual Tyler Awards of the New York Section were presented at the May meeting of the section. Steve Tyler, former secretary of the Institute, presented the awards named for him to Warren McCabe, left above, for the best book on chemical engineering for the year, and Elmer L. Gaden, Jr., above right, for the best article published in a periodical during the year.

Fansteel

Corrosionomics

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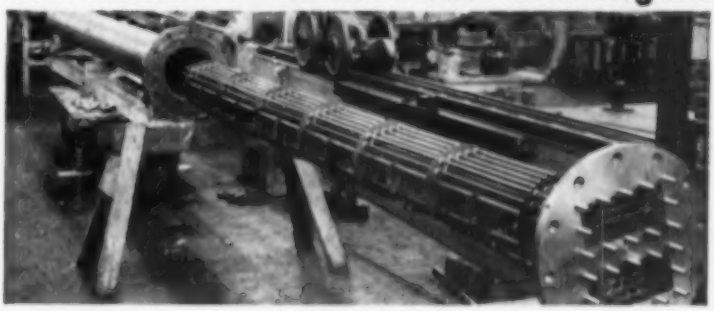
A JOURNAL OF USEFUL INFORMATION FOR THE SOLUTION OF CORROSION PROBLEMS

Tantalum "U" Tube Heat Exchangers



*By A. T. Bergstrom**

Since the tube side of shell and tube type heat exchangers is the "tightest" side, tantalum exchangers of this type are usually constructed so that the corrosive liquid being handled passes inside the tantalum tubes rather than around them.

Conventional fixed tube sheet exchangers are limited to tantalum tubes 6 or 8 feet long because of the 2½ to 1 ratio of thermal expansion coefficients of steel and tantalum. Further, examination and cleaning of the outside of the tubes is difficult.

The "U" tube or hairpin type tube bundle consists of tubes bent to a "U" shape with the both ends fixed in one tube sheet, so that with proper manifolding, the liquid enters and leaves the tubes at the same end of the exchanger. The exchanger can be made in a wide range of sizes by varying tube length and diameter, number of tubes, and shell dimensions.

The advantages: (1) elimination of the differential expansion problem, (2) ease of inspection and cleaning of bundle and shell, (3) no internal gaskets, and (4) elimination of one tube sheet and its tantalum protective flange. The disadvantages: (1), difficulty of replacing individual tubes on inside bends and (2) inability to clean mechanically the interior of tubes at the bends. (Tantalum, however, can easily be cleaned with hydrochloric acid.) The advantages, in most instances, obviously outweigh the disadvantages of this type of construction.

The seamless tantalum tubes are thinwall; 0.020" for ¼" OD tubes for 150 psig steam pressure in the shell, and 0.015" for ½" OD tubes for 200 psig steam pressure provide a safety factor of five. The tube bundle is held in a series of segmented steel baffles fastened together with tie rods.

Teflon** grommets support the tubes in the baffles and permit their free movement.

The tubes are rolled into the steel tube sheet through copper ferrules, and after pressure testing, are arc welded to the tantalum tube sheet facing flange. Tantalum lined headers are bolted to the tube sheet, Teflon gaskets being used to provide a tight, leakproof joint.

*Chief Design Engineer, Chemical Equipment Division, Fansteel Metallurgical Corporation

**Registered trade mark, E. I. du Pont de Nemours & Co., Inc.

Free Tantalum Test Kit

A corrosion test kit, available without charge to research technicians, contains both tantalum sheet and wire. Request it on your letterhead.

The above condensation is typical of articles which appear in CORROSIONOMICS, a Fansteel publication. Mail us your name for inclusion on our mailing list.

For further data on the above, write:

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CHEMICAL EQUIPMENT DIVISION

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The Elliott line of strainers also includes Single, and Self-Cleaning Strainers in sizes ranging from 1" to 24", and with straining perforations from 3/8" down to fine wire mesh. For further details contact your local Elliott District Office or write Elliott Company, Jeannette, Pa.

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News of the Field
FROM LOCAL SECTIONS

(*Continued from page* 101)

Univ., Boston, Mass., evaluated the educational systems of the United States and Europe. In Europe, the secondary schools insist on a good general education plus languages and a heavy schedule of mathematics. In general, European students are more serious minded and intent upon learning, and colleges will accept only those who have passed a maturity examination. Teachers in Europe have prestige comparable to doctors and lawyers, are well paid, must maintain high standards.

Economics and Transportation

Profit is a function of both sales volume and production cost and engineers are sometimes so intent on the cost factor that they lose sight of the salability of the product, H. S. Dye, professor of economics at the Univ. of Tenn., told the April meeting of the **Knoxville-Oak Ridge Section** (*R. W. Horton*). Dye went on to discuss the effect of fluctuating demand on the choice of optimum plant size, and to enumerate the many factors influencing the relative costs of labor and capital.

H. D. Midkiff of Tennessee Eastman's traffic department bluntly pointed out to the April meeting of the **East Tennessee Section** (*A. J. Peacock, Jr.*) that chemicals actually have very little value at the point of manufacture but must be shipped to the point of use to realize their value. In transporting chemicals, Midkiff explained, several questions must be answered: 1) What is to be shipped; 2) How much is to be shipped; 3) The destination of the shipment; 4) When does the shipment have to be at its destination? The first question includes the proper freight classification for determining the proper rates. Dangerous articles are described and classified by the ICC with the labeling, loading and unloading regulations designated for all classes. These regulations must be observed in the transportation of chemicals falling into the dangerous category. The size of the shipment, the destination, and the delivery time stipulations determine the mode of transportation, but each shipment must be considered separately and on its own merits.

Psychology—Polyethylene

Creativity from the psychologist's point of view is the process of "play-

(*Continued on page* 104)

PROVING

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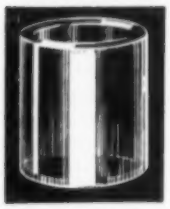

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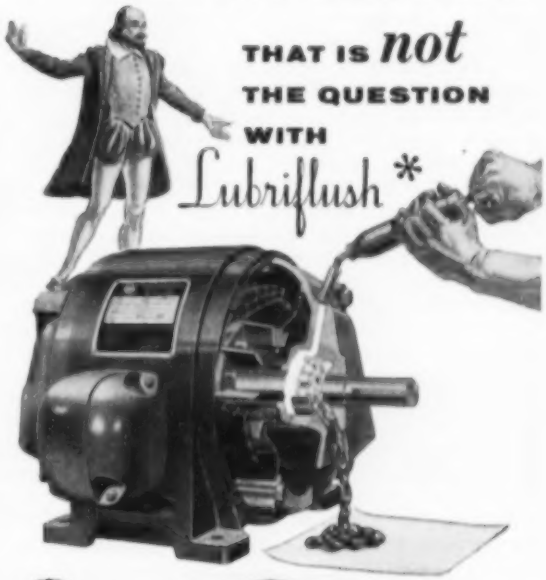

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says keynoter at recent Akron meeting:

CHEMICAL ENGINEER HAS BEST OPPORTUNITY OF ALL IN INDUSTRIAL POLLUTION CONTROL

The chemical engineer has the opportunity to accomplish more than any of the other professions in the field of industrial pollution control. So said Roy F. Weston (Weston & Eckenfelder Associates) in delivering the keynote address before the recent six-section one-day meeting on industrial pollution control held in Akron, Ohio. Weston went on to explain that the chemical engineer cannot do the job alone, that it is his ability to draw upon and bring together the work of such specialists as chemists, biologists, sanitary engineers, and others that makes his contribution so necessary.

The area of *prevention* was cited by Weston as being the one in which most can be accomplished in the future. This area is another "natural" for the chemical engineer at the time of process design, at which time it is not only cheaper, but also frequently easier, to sell pollution control than it is after the plant is built and the capital appropriation needed for control facilities assumes a sizeable proportion of the capital allocation for the completed plant.

Often, continued Weston, the cost of needed prevention facilities at the time of design of a new plant amounts to only two to three per cent of the total capital appropriation requested—well within the range of competitive bidding.

Warning was given by Weston, lest one consider that the only way to use the services of the chemical engineer in the field of industrial pollution control would be in process development and design. Today's chemical engineers also function in the approval of processes and in management of operations, having become a most important professional group in top management. In these roles, Weston believes the chemical engineer can be an important factor in the decision to *do something*, to do the right, the economic thing in preventing or controlling pollution. (Pictures on pages 110-111.)

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News of the Field
FROM LOCAL SECTIONS

(Continued from page 102)

ing around." With this fresh approach to his subject, The Psychological Factors in Creativity, R. W. Wallen, Creelman Associates, Cleveland, went on to explain to the April meeting of the **Northeast New York Section** (*W. S. Frank*) that people frequently indulge in creative effort purely for the pleasure of the creative process without concern for the end product of the process. With this concept of creativity, Wallen doubted that industry really wants creativity. As soon as industry defines a specific research objective, the key "playing around" ingredient is at least partially lost. Wallen chided the "fadism" of industrialists who have suddenly discovered creativity and are pushing it hard without really understanding it. He went on to discuss the four primary factors which hinder creative effectiveness: 1) Lack of education and experience is probably the most overlooked hindrance—a mind well-stocked with knowledge is the most fertile soil for new ideas. 2) Lack of motivation is frequently cited as a hindrance, but Wallen believes all people have a natural motivation to create. The problem is not to motivate people but rather to remove the blocks. For example, don't block motivation by ignoring the emotional impact of project cancellations. 3) The hindrance of "set" or fixed patterns is well recognized. 4) Fear of thought is a mental block that stems from a subconscious fear of criticism. This, Wallen feels, is the big weakness of brainstorming which prohibits external criticism but cannot prevent self-criticism and repression. Although management often does not really understand creativity, unless it is creative and receptive to new ideas the whole organization will languish.

The completed multi-million-dollar low pressure polyethylene plant of W. R. Grace will produce 50 million pounds a year, according to A. J. Bruno, Jr., of Grace, speaking before the March meeting of the **El Dorado Section** (*G. D. Rucker*). The plant, being built at Baton Rouge by Fluor with the help of Phillips Petroleum, owner of the process, will cost about $18.5 million, will get its ethylene from the nearby Esso refinery at a price of about 5¢ a pound. Low pressure polyethylene is polymerized with a catalyst and solvent at 500 to 550

(Continued on page 106)

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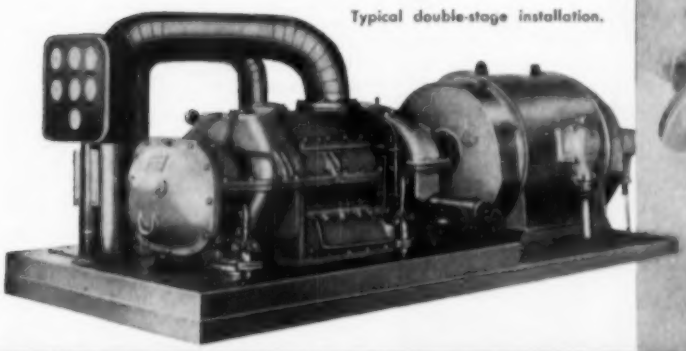
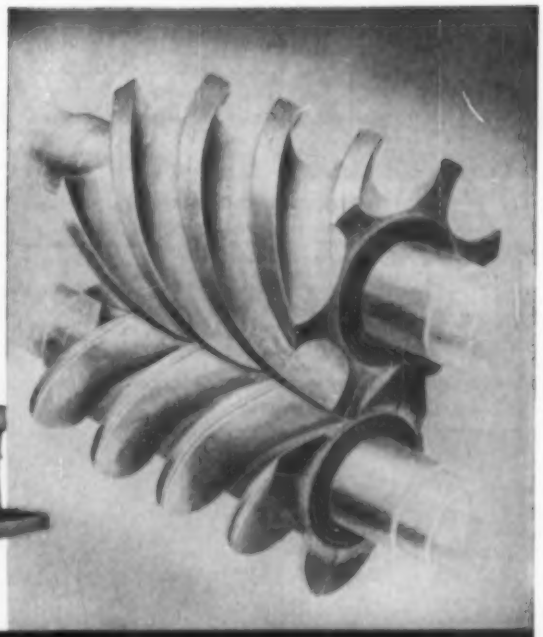
for oil-free handling of air and many other gases. Flow rates range from 350 to 15,900 cfm. Pressures up to 155 psia.



Typical double-stage installation.



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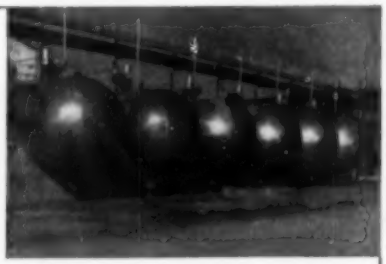

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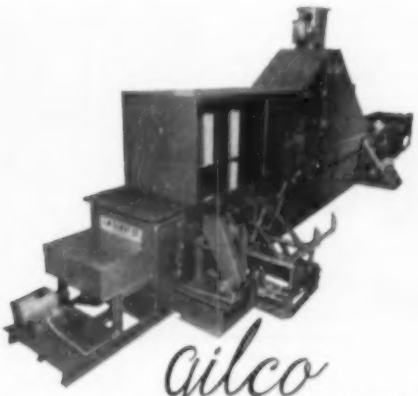

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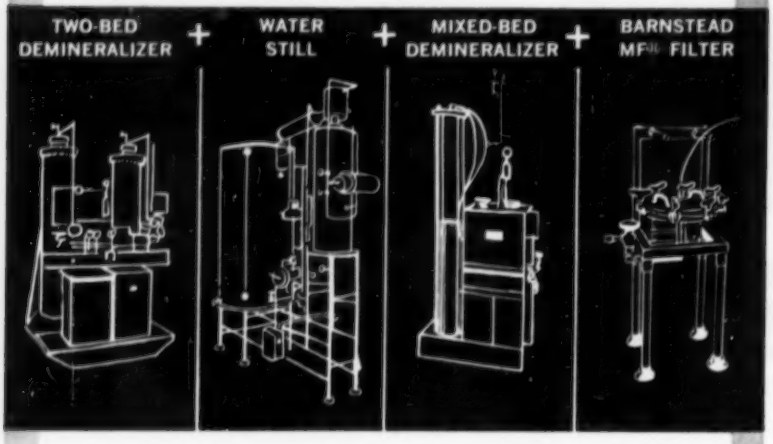

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News of the Field
FROM LOCAL SECTIONS

(Continued from page 104)

pounds pressure in all carbon steel equipment. Aluminum and stainless are used in the finishing sections to assure purity. There is no corrosion problem. As compared with the Ziegler process, the Phillips process seems to have fewer difficult processing problems, according to Rucker.

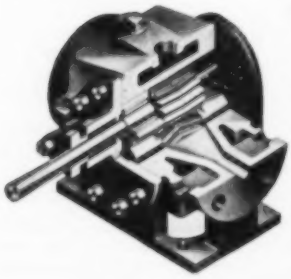
Also Meeting

Western Massachusetts (*R. T. Bogan*) in March heard F. C. Durant III of the Arthur D. Little Co. discuss the forthcoming activities of the International Geophysical Year and the Space Satellite program. Observations for the IGY will be made from all land surfaces and some 70 scientific research ships. A major aspect of the IGY is the launching of the space satellite which will travel about the earth at about 18,000 miles an hour. . . **Oklahoma Section** (*E. R. Beck*) listened to a talk by K. Banes of Southwestern Bell Telephone Co. on the early warning radar system in Northern Canada. Banes explained that our national defense depends on an efficient warning system which will give us enough time to prepare for an attack. The need justified the decision to build the DEW-line in Northern Canada. The problems involved were shown in a film, *Arctic Mission*. . . **Northern California** (*J. C. Ornea*) discussed Modern Techniques in Petroleum Refining at its February meeting. The speaker, M. J. Sterba, head of Universal Oil Products' Engineering Research and Development Department, outlined a process scheme for increasing the octane rating furthier

(Continued on page 109)

A.I.Ch.E. executive secretary F. J. Van Antwerpen presents the formal charter which gave the new Syracuse Section permanent affiliation with A.I.Ch.E. Van Antwerpen made the formal presentation at the recent May meeting of the section which was organized in April, 1956. Receiving the charter is section chmn. H. P. Munger, Syracuse Univ., and watching is section vice-chmn. R. A. Hiserodt, Solvay.

DON'T GIVE UP
when viscous liquids cause pumping problems . . .



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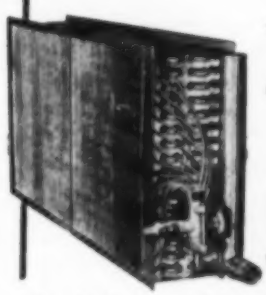

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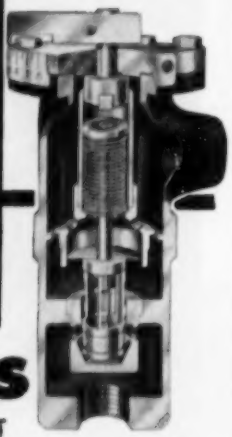

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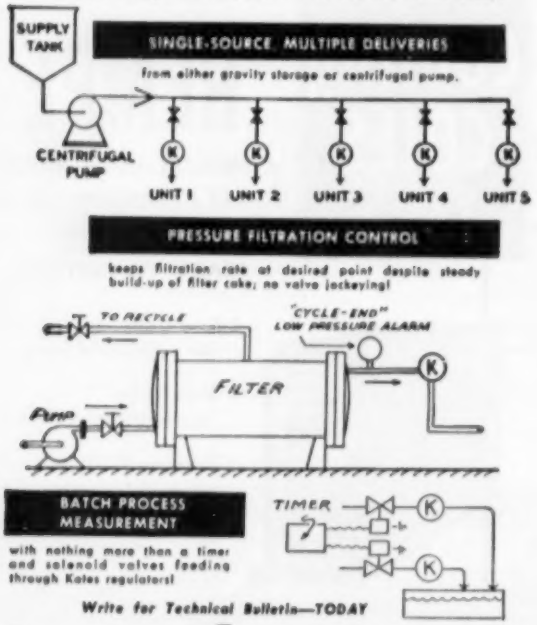

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CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 8 of the Constitution of A.I.Ch.E.

Objections to the election of any of these candidates from Members and Associate Members will receive careful consideration if received before July 15, 1957, at the office of the Secretary, A.I.Ch.E., 25 West 45th Street, New York 36, N. Y.

Member

Anastasio, Anthony J., *New Brunswick, N. J.*
Anthes, John A., *Pittsburgh, Pa.*
Austin, J. M., *Pittsburgh, Pa.*
Berglund, Lawrence W., *Kansas City, Mo.*
Berry, Kay L., *Englewood, Colo.*
Bulkowski, H. Harold, *Springfield, Pa.*
Butts, Durain C., *Akron, Ohio*
Canney, C. F., *Pittsburgh, Pa.*
Cech, Charles J., *Wood River, Ill.*
Chapman, W. D., *Saginaw, Mich.*
Ebersole, Alvin J., *Downey, Calif.*
Engle, L. F., *New Orleans, La.*
Fitch, Charles M., *Houston, Tex.*
Fondrk, V. V., *Jeannette, Pa.*
Gans, Manfred, *Leonia, N. J.*
Gibson, E. Lacy, *Whiting, Ind.*
Graeter, Raymond G., *Cambridge, Mass.*
Guillory, M. J., *Baton Rouge, La.*
Hendrickson, John R., Sr., *Camden, N. J.*
Hermanson, D. A., *St. Louis, Mo.*
Hicks, Harold E., *Hattiesburg, Miss.*
Hosty, Jack A., *Pine Bluff, Ark.*
Hugill, J. T., *Norwalk, Conn.*
Jackson, Leroy, Jr., *Texas City, Texas*
Jackson, William B., *Library, Pa.*
Jost, John A., *E. Aurora, N. Y.*
Junge, James F., *Jenkintown, Pa.*
Kennedy, Klem K., *Sepulveda, Calif.*
Ketzlach, Norman, *Richland, Wash.*
Kiopekly, George, *San Mateo, Calif.*
Maddock, William T., *Robinson, Ill.*
Martin, Monroe D., *Idaho Falls, Idaho*
Miller, Benjamin, *New York, N. Y.*
Minkin, Morris B., *New York, N. Y.*
Moller, Denny D., *Pittsburgh, Pa.*
Morrell, Gerald, *Olmsted Falls, Ohio*
Murphy, George R., *Chesterton, Ind.*
Nielsson, Francis T., *Morton Grove, Ill.*
Paradiso, Sam J., *Kalamazoo, Mich.*
Pfeiffer, Fred, *Boulder City, Nev.*
Pounds, Arthur M., *Elyria, Ohio*
Reichenbach, George S., Jr., *Sparrows Point, Md.*
Reidel, John C., *Tulsa, Okla.*
Ristaino, Antonio J., *Annapolis, Md.*
Ruark, C. S., *Decatur, Ala.*
Scharman, R. P., *Collingswood, N. J.*
Schumacher, Frederick G., *Wilmington, Del.*
Schwaegerle, Edward G., *Elyria, Ohio*
Seabury, A. D., *Gibsonia, Pa.*
Shelton, Frederic J., *Seattle, Washington*
Sienkiewicz, Boleslaw, *Pearl River, N. Y.*
Sorgato, Ippolito, *Padova, Italy*
Stromquist, Donald M., *Bountiful, Utah*
Teller, Aaron J., *Gainesville, Fla.*
Thomas, William D., *Toledo, Ohio*
Thompson, H. Leroy, *Birmingham, Ala.*
Vahldieck, Nathan P., *Milwaukee, Wis.*
Ward, Harry W., *Cranford, N. J.*
Williams, Jack C., *New York, N. Y.*
Wurzbach, Clinton O., *Edmonton, Alberta, Can.*

Associate Member

Ambrose, Edward A., *St. Paul, Minn.*
Bowman, Charles W., *Baltimore, Md.*
Breyfogle, P. L., *Decatur, Ill.*
Bryson, Harry W., Jr., *Tacoma, Wash.*
Couper, Colin C., Jr., *Army Chemical Center, Md.*
Cross, Alan, *Pittsburgh, Pa.*
Crowther, Sam, *Pasadena, Tex.*
Davidson, Alan K., *Memphis, Tenn.*
Devaney, Harold E., *Westfield, N. J.*
Gessner, Adolf W., *Pittsburgh, Pa.*
Gibson, Douglas A., *Lake Jackson, Tex.*
Greer, Richard J., *Ponca City, Okla.*
Griffith, Samuel, *La Marque, Tex.*
Hayward, Charles R., *St. Louis, Mo.*
Hester, David B., *Cincinnati, Ohio*
Hinken, Lawrence R., *Decatur, Ala.*
Holan, Elmer W., *Lake Jackson, Tex.*
Holden, John F., *Toms River, N. J.*
Honohan, Edward J., *Jamaica, N. Y.*
Hook, Glenn M., *E. St. Louis, Ill.*
Huling, Gene Paul, *Corapolis, Pa.*
Josvanger, Charles F., *Portsmouth, Ohio*
Kenney, William F., *Upton, N. Y.*
Kildea, John, *Pittsburgh, Pa.*
Kirberg, J. Ronald, *Cuyahoga Falls, Ohio*
Klein, John D., *Baltimore, Md.*
Kline, Paul E., *Midland, Mich.*
Kmak, Walter S., *Old Bridge, N. J.*
Koerner, Ernest L., *Niagara Falls, N. Y.*
Koretzky, Joseph, *Brooklyn, N. Y.*
Langan, Thomas E., *Phila., Pa.*
Lurie, Robert M., *Waltham, Mass.*
Malcomson, A. J., *Mentor, Ohio*
Manske, W. J., *St. Paul, Minn.*
Mattana, John L., *New York, N. Y.*

LOCAL SECTION

(*Continued from page* 106)

toward levels which may be required in the near future. The method involves a process whereby C_5 and C_6 fractions would be separately isomerized and the isomer products then blended with Platformate made from the C_7 plus fraction. . . **Philadelphia-Wilmington** (*L. G. Magill*) held its Ladies Night in February and the featured speaker was Ruth Patrick, Philadelphia Academy of Natural Sciences' expert on the study of fresh waters and their physical, chemical and biological factors. Dr. Patrick spoke of her adventures on an aquatic survey of the Amazon River. . . **Texas Panhandle** (*C. M. Oktay*) invited H. O. Hodson, vice-president of engineering and operations at the Southwestern Public Service Co., to speak at its March meeting on what Engineers Owe the Public. . . . **Detroit** (*R. D. Stevenson*) at its May meeting heard about the development of fibers from Egyptian times up to the modern synthetic fibers manufactured by Chemstrand where the speaker, R. W. Work, is director of Fiber Development.

CANDIDATES

(*Continued*)

McCabe, Earl A., Jr., *Pittsburgh, Pa.*
McNeely, James B., *Highland Park, N. J.*
Migliatto, A. L., *Bedong, Kedah, Malaya*
Mirenda, John T., *New York, N. Y.*
Pearlman, Samuel, *Philadelphia, Pa.*
Pement, Fred W., *Pittsburgh, Pa.*
Plombon, Julian J., *St. Paul, Minn.*
Pollock, Fred E., *Memphis, Tenn.*
Powell, H. W., Jr., *Tulsa, Okla.*
Ratcliffe, Stanley R., *Mentor, Ohio*
Roane, S. Boyd, *Donaldsonville, La.*
Robinson, Alexander H., *Schenectady, N. Y.*
Rodriguez, Harold V., *Baton Rouge, La.*
Root, William L., 3rd, *Bethlehem, Pa.*
Ross, Laurence W., *So. Charleston, W. Va.*
Scharf, E. Jonathan, *Somerville, N. J.*
Schmitt, Emil, Jr., *Easton, Pa.*
Schroder, Malcolm C., Jr., *Aiken, S. C.*
Senour, Richard T., *E. Alton, Ill.*
Shaver, Charles C., Jr., *Houston, Tex.*
Shingleton, Gordon D., *Lutherville, Md.*
Shinnar, Reuel, *L. I. C., N. Y.*
Shouse, C. W., *Big Spring, Tex.*
Slyker, Richard A., *Pasadena, Tex.*
Summers, Frank V., *Scotia, N. Y.*
Tardif, Richard E., *Rochester, N. Y.*
Thorpe, John A., *St. Paul, Minn.*
Trostel, Albert O., *Milwaukee, Wis.*
Trowbridge, William Otis, *St. Paul, Minn.*
Vannoy, Thomas R., *Seagraves, Tex.*
Van Sandt, J. H., *Cushing, Okla.*
Volkmann, Ronald J., *Cincinnati, Ohio*
Wheatley, T. A., *Decatur, Ill.*
Wingfield, Harold T., *White Bear Lk., Minn.*
Winslow, Charles E., Jr., *W. Norfolk, Va.*
Witter, Ray E., *Trenton, Mich.*
Wolford, Fred V., *Austin, Tex.*

Affiliate

Chakraborty, Ajit Kumar, *Salford, Lancashire, U. K.*
Eby, Donald L., *Collinsville, Ill.*
Frodey, David H., *Charleston, W. Va.*

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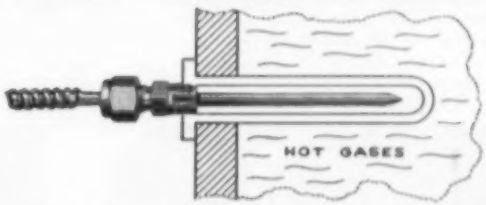

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Write for Bulletin 325-V.

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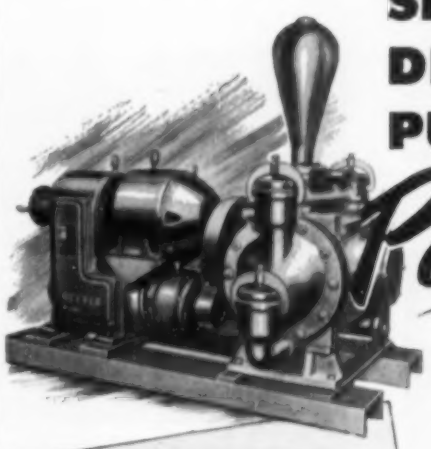

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CEP CAMERA

MISSILE FUELS

Will be subject of two symposia at the Baltimore A.I.Ch.E. meeting in September. Shown here are some of the leaders in missile fuels development at the recent Commercial Chemical Development Association Meeting on this subject. Some of these men will be speakers in Baltimore.

David Altman (Aeroneutronics), Barnet Adelman (Ramo Woolridge), and Arthur Stosick (Union Carbide Research Institute) discuss Adelman's appeal to the chemical industry to keep in close touch with the needs of the missile industry.

Robertson Youngquist (Reaction Motors), H. W. Richey (Thiokol), and Richard B. Canright compare the nitric acid-JP-kerosine fuel of NIKE with the possibilities of liquid hydrogen, which Youngquist reported has a habit of condensing oxygen from the air into itself, thus creating explosion hazards.

J. J. O'Connell (Amoco Chemicals), E. A. Weilmuenster (Olin Mathieson), Lyman Bonner (Hercules), and J. F. Tormey (Rocketdyne) chat about Tormey's classification of fuels and Weilmuenster's prediction of boron derivatives of significance to the chemical industry.

INDUSTRIAL POLLUTION

Control was subject at recent six-section one-day meeting in Akron (shown here), plus cooperative A.I.Ch.E.-Air Pollution Control Association meeting in St. Louis.

C. A. Snavely and J. E. Clifford (both Battelle) hear Roy Weston (Weston & Eckenfelder Assoc.) explain his meeting-keynote theme that "the chemical Engineer has the opportunity for accomplishing more than any others . . . in the field of industrial pollution control." Weston is chairman of A.I.Ch.E.'s Pollution Control Committee.

R. J. Ruff (Catalytic Combustion Corp.) brought to Akron data on the performance of large-scale catalytic fume combustion units.

Wm. W. Ellis (M & R Dietetic Labs), C. L. Parish (Columbia-Southern, Barberton), and R. E. Lynn, Jr. (B. F. Goodrich Research) discuss session on stream pollution which Lynn chairmanned.

NEWARK

C. F. Savage, Consultant on Professional Relations, General Electric, answers questions following his talk on "Intangible Aspects of Professional Employment," a part of the session on "The Engineer as a Professional Man" at the one-day meeting of the New Jersey Section, A.I.Ch.E., at Newark May 14.

Plastic piping (left) in interior of one of 98 rotary filters installed in Chicago's sewage system in 1948. Liquid is water, ferric chloride, and various acids. (Courtesy U. S. Rubber.)

Scene (above) at Searles Lake, California, when American Potash & Chemical Corporation conducted tour for visitors from Pacific Northwest pulp and paper industry. Pipeline (background) transports chemical brine five miles to Trona, where it is refined.

Lynn, W. L. Otto (Firestone, Akron), George Blum (Goodyear, Akron), Ellis, and Parish. Bloom told of his experiences in organizing the technical program for the Akron meeting, attended by more than 160. Blum is secretary of A.I.Ch.E.'s Pollution Control Committee.

What is it? Answer: sphere coated with Celanese's new high-gloss water-thinned latex paint, made of polyvinyl acetate emulsion. Believed the first commercially-introduced, Celanese predicts that such paints will be used on all automobiles by 1965.

people

President of the recently-formed Olin Mathieson International Corp. is **Henry A. Arnold.** Arnold will be responsible for all of Olin Mathieson's overseas activities including production and marketing.

Arnold

New research and development manager for Acheson Colloids Co., Port Huron, Mich., is **Arthur J. Stock.** Before joining Acheson, Stock was project director for Chicopee Manufacturing Corp., Springfield, Mass.

Robert B. Beckman promoted to professor of chemical engineering at Carnegie Institute of Technology. Beckman, who is supervisor of the Callery Chemical Co. research contract at Carnegie, joined the faculty in 1946.

New executive assignments at Spencer Chemical Co. include **Robert A. Byorum** as chief engineer and **Robert W. Hogeboom** as assistant chief engineer.

William Weltner, Jr. and **Floyd I. Scherber** are new members of the staff of the newly-formed Union Carbide Research Institute.

New member of the process development staff of the Toilet Goods Division at Procter & Gamble is **Robert A. Cody.**

Hooker Electrochemical Co. announces appointment of **Robert F. Schultz** as works manager, Niagara Falls. Schultz was formerly production superintendent of the Hooker Niagara Falls plants, including the P-31 plant at Model City. Also at Hooker, Niagara Falls, **Maynard L. Parker** has been named production superintendent and **Barrett B. Brown** becomes assistant production superintendent.

W. B. Franklin is one of the 14-member Advisory Council for the newly-formed Engineering Foundation of the College of Engineering at the University of Texas. Franklin is presently acting manager of the Refining and Research Division in Humble Oil & Refining Company's executive development program.

Franklin

Dunning

Ranald G. Dunning, formerly project engineer and project analyst at Merck & Co., joins Metalwash Machinery Corp., Elizabeth, N. J., as manager of research and development.

Paul Bumble, formerly with General Foods Engineering Research, has joined Wyssmont Co. as research and designing engineer in the Technical Section.

Blaw-Knox announces appointment of **Bruce Alexander** as manager of technical services at its offices in Washington, D. C. Alexander has been with Blaw-Knox since 1944.

Promotions in Research and Development Department of Ethyl Corp. at Baton Rouge include: **W. Burke Grandjean** to superintendent of business information; **Merle L. Gould** to assistant director in process design; and **J. B. Bingeman** to acting supervisor in process design.

James L. Walker has joined Purvis & Gertz, Inc., consulting engineers, Dallas, Texas, as staff consultant for the petroleum refining and petrochemical industries.

Robert A. Brown, recently associated with the Campbell Soup Co., named to staff of Whiting Research Laboratories, Standard Oil Co. (Indiana).

National Research Corp. announces promotion of **James H. Gardner** and **Arthur G. Walsh** to be assistant directors of their Research Division.

Joseph A. Brink, Jr., honored with the Gaston du Bois award of the Inorganic Chemicals Division, Monsanto Chemical Co., for outstanding research accomplishments during 1956.

John P. Hyde promoted to position of operations manager for Diamond Alkali's Silicate, Detergent, Calcium Division. Hyde joined Diamond Alkali in 1951.

Thomas G. Fox appointed assistant director of research in Mellon Institute. He will head the Institute's programs of polymer research.

Graham C. Mees has been appointed president and **John C. Hecker** has been named vice-president and general manager of the Distillation Products Industries Division of Eastman Kodak Co.

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William A. Leitner joins staff of Overseas Development Division of the Procter & Gamble Co.

Myron G. DeFries has become a member of the Chemistry Division of the Atlantic Research Corp., Alexandria, Va. DeFries has been a chemical engineer with Rohm & Haas and with Houdaille-Hershey Corp.

New vice-presidents of Union Oil Co. of California are **Basil P. Kantzer** and **Charles S. Parker.**

Joseph McGaw and **Martin Gurvitch** have joined the staff of the Research & Development Department, Barrett Division, Allied Chemical & Dye. They will both be involved in applications research on phenolic resins.

Raymond Ewell, former assistant director of the National Science Foundation, named as vice chancellor for research and professor of chemistry at the University of Buffalo. Ewell recently served as consultant to the India Ministry of Commerce and Industry in New Delhi.

F. G. Stech promoted to group leader responsible for industrial engineering functions at the Institute, West Va., plant of Union Carbide Chemicals Co.

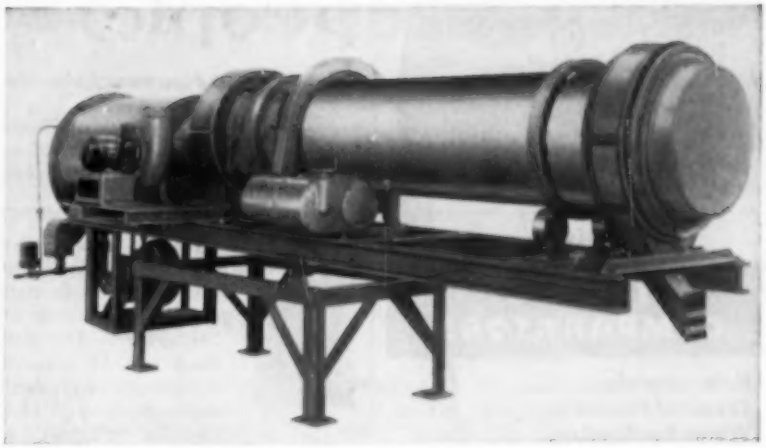
Warren L. McCabe, administrative dean of the Polytechnic Institute of Brooklyn, receives Tyler Award of the New York Section of the A.I.Ch.E. A past president of the A.I.Ch.E., McCabe has served on the faculties of M.I.T., Carnegie Institute of Technology, and the University of Michigan.

Executive changes at Vitro include election of **G. Russell Tatum,** division general manager, and **William A. Bain, Jr.,** director of Vitro's West Orange, N. J., Laboratories, as president and vice president, respectively, of Vitro Laboratories. Also at Vitro, **Norman A. Spector,** vice-president of Heavy Minerals Co. and assistant general manager of Vitro Engineering Division, has been named vice president of Vitro Corp. of America.

Spector

John Kempf joins technical staff of Furane Plastics as product development manager of adhesives and coatings. Kempf was formerly associate director of research at U. S. Stoneware.

(Continued on page 114)



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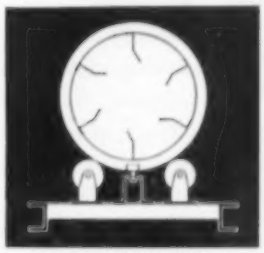
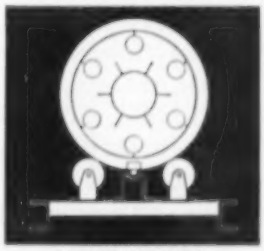
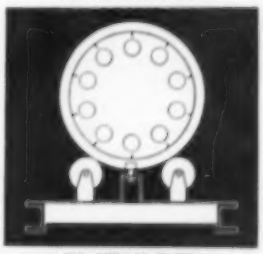


XH-XF SINGLE-SHELL



XB DOUBLE-SHELL



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people

Joseph H. Cox joins staff of Chemicals Development Division of Esso Research and Engineering Co., Linden, N. J.

Watson

Kenneth M. Watson, former vice president of Pure Oil Co., appointed to staff of Illinois Institute of Technology. He will teach and do research in kinetics and thermodynamics in the Chemical Engineering Department.

B. F. Goodrich Chemical promotes **A. R. Webber** to new assignment in economic planning of production operations. Webber was formerly a process control engineer in the company's Product Improvement Department.

New product manager-plastics for the FMC Organic Chemicals Division of Food Machinery and Chemical Corp. will be **Richard M. McFarland.**

Battelle Institute announces election of **Edward E. Slowter** as vice-president. Slowter has been a member of the Institute's technical and executive staff since 1936.

David Christison, assistant director of the Technical Department of Socony Mobil Oil Company's Paulsboro, N. J., refinery, has been awarded a Sloan fellowship to participate in the executive development program at M.I.T.

Howard W. Martin is one of several Monsanto research scientists to be granted leave of absence for academic study for the year 1957-58. Martin is a chemical engineer in the Monsanto Plastics Division at Texas City.

Salvatore S. Stivala, instructor in chemical engineering at Stevens Institute of Technology, awarded one of first Science Faculty Fellowships provided by the National Science Foundation.

Promotions at the Institute, West Va., plant of Carbide and Carbon include: **J. H. Field** as area supervisor of the polyethylene area; **D. P. Heath** and **P. W. Pontius** as department heads, polyethylene area.

(Continued on page 120)

MISCO

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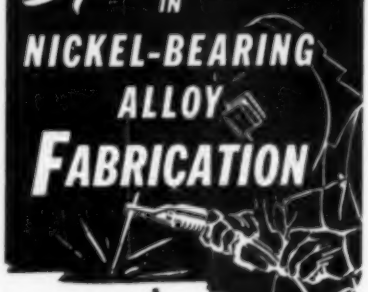

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REFRIGERATION ENGINEER

Minimum BS/ME or equivalent. At least 5 years' experience in design and analysis of process cooling and air conditioning refrigeration systems, particularly in testing and performance analysis of compressors, drives, controls and heat exchangers. Duties include consulting for Engineering and Plant Operations on analysis, testing and development of refrigeration systems. Engineer will maintain liaison with Company and outside personnel. Travel to plant and other locations required. Must be articulate in speech and writing and be able to perform technical and economic analyses with minimum supervision. Should have personal traits to fit him for consulting, liaison and supervision, potentially in prominent position.

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Successful applicant will analyze existing and proposed chemical processes for utilization of petroleum processing equipment and methods for obtaining greater yield and lower equipment investment, particularly with respect to hydrocarbon processes. Typical operations to be evaluated include solid fluidization, absorption, reforming, and catalysis. This requires broad familiarity with equipment such as hypersorbers, distillation columns, cracking furnaces, low temperature refrigeration systems, and compressors. Other duties include trouble-shooting and economic evaluation of alternative processes and equipment.

PRE-DESIGN ANALYSIS

Duties are: assistance in the preparation and analysis of basic information for design of operating units and supporting facilities in order to obtain optimum performance with minimum investment and operating costs; preparation of flow sheets; evaluation of process alternatives; selection and approximate sizing of equipment; and establishment of heat and material balances. Position requires five or more years of experience in equipment selection, economic evaluation of processes, and development of information for design of industrial facilities.

PLASTICS ENGINEER

BS engineering or chemistry, minimum. 5-10 years' experience in plastics engineering for process equipment and auxiliary services. Duties include consulting services covering development, evaluation, selection, specification and fabrication of plastics for chemical process equipment and auxiliaries; investigations of failures and recommendations of remedial measures.

MATHEMATICIAN for Operations Analysis

Duties include: mathematical formulation of complex engineering and scientific problems in form amenable to numerical analysis; non-linear regression analysis of production data, using theoretical knowledge of chemical and engineering mechanism to select form of production equations; and development of applied methods to handle new industrial problems in matrix mathematics, numerical analysis, etc., being created by the availability of large scale digital computers. Operations are on a company-wide basis. Desired qualifications: a PhD or equivalent in mathematics or physical science with demonstrated interest in and experience with numerical analysis or machine computation.

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YOU CAN AVOID BECOMING CHANNELED into one phase of engineering by working with LINDE, a growing company. As part of LINDE's program to develop better personnel for future management and for creative engineering, our engineers are asked to work in a variety of technical activities. These engineering positions place a premium on individual initiative, since routine operations are covered by experienced technicians. Realize your maximum potentials. Write to J. J. Rostosky, Dept. CP-6, Speedway Laboratories, Linde Company, Division of Union Carbide, P. O. Box 8237, Indianapolis 24, Ind. For additional information on opportunities in the northeast, see our ad on page 42.

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SITUATIONS WANTED

A.I.Ch.E. Members

CHEMICAL ENGINEER—Ph.D.—Ten years' responsible experience process development, development-production liaison, and plant start-ups. Publications and honoraries. Desire responsible position with definite opportunity for advancement to administrative or management level. Box 4-6

CHEMICAL ENGINEER—Age 32. B.S.Ch.E. 1948. Nine years' experience in production supervision in large plant manufacturing heavy chemicals. Desire similar position opportunity for advancement. Must be in area with good living conditions. Box 5-6.

CHEMICAL ENGINEER — Thirteen years' total experience. Process, project engineering,—seven years. M.Ch.E. 1951. Plant, process design and operation. Chemical, polymer and engineering research. New York City location. Minimum salary $11,000. Box 6-6.

B.S.Ch.E.—Some graduate study. Age 40. Five years' industrial experience, vinyl and alkyd research and pilot plant development. Twelve years' teaching unit operations and industrial chemistry in mid-western college. Desire teaching or industrial position, preferably Florida. Box 7-6.

PROJECT MANAGER—Twenty years' experience, fifteen in project engineering. Head of department handling $40,000,000 annual business. Present salary approximately $14,000. Please outline proposition. Box 8-6.

CHEMICAL ENGINEER—B.Ch.E. 1952, veteran, married. Five years' experience in process and development work. Desire project supervision in development field in Michigan, Wisconsin or Minnesota area. Base salary expected $7,500. Box 9-6.

CHEMICAL ENGINEER—Nine years' experience in production, cost control, planning, trouble-shooting. Have worked with organics, solvents, inorganics, fine chemicals and pharmaceuticals. Some process engineering and development. Will consider line or staff assignment. Prefer New York area. Box 10-6.

CHEMICAL ENGINEER—M.S. Age 34. Nine years one company. Seek supervisory job in process development, industrial products research, or in technical sales including overseas. Experience in synthetic yarn manufacture and over four years' in atomic energy. Present salary $10,200. Box 11-6.

CHEMICAL ENGINEER—B.Ch.E. New York University, 1951. Diversified background including process and production engineering studies, composite propellants. Product development, compounding of natural and synthetic elastomers, trouble-shooting and quality control (statistical); textile experience, dye application. Box 12-6.

CHEMICAL ENGINEER—Ph.D. 33. Ten years' varied process research, development, project engineering (chemical, petroleum, nuclear), including supervision. Seeking interesting position in research, development or teaching. Prefer California. Box 13-6.

CHEMICAL ENGINEER — B.Ch.E. 1952, M.S.Ch.E. June 1957. Three years' experience hydraulic and pneumatic systems, design and pilot plant research and development, some supervisory experience. Desire position in process or production engineering in New York Metropolitan area. $7,000. Box 14-6.

TECHNICAL DIRECTOR — Ph.D. Many years' experience in direction and administration of research and development along broad chemical and engineering lines. Top level production experience, corporate planning, technical assistant to president. Box 15-6.

(*Continued on page* 121)

CHEMICAL ENGINEER
OR
PETROLEUM ENGINEER
M.S. or PH.D.

To direct product research on oil and gas field equipment. Engineer should have experience in natural gas or petroleum processing and possess a good background in thermodynamics.

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Please send complete information and photograph to **Orval W. Groves, Employment Supervisor,** at address shown below:

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CHEMICAL ENGINEER

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Work consists of translating process requirements into completed operating pilot plants and includes mechanical design, proper application of equipment, instrumentation, cost estimation, scheduling, materials procurement, field supervision of construction, initial operating shake-down, and new equipment development.

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Give full details of education, experience, desired salary, availability date and references. All inquiries will be considered promptly and held confidential.

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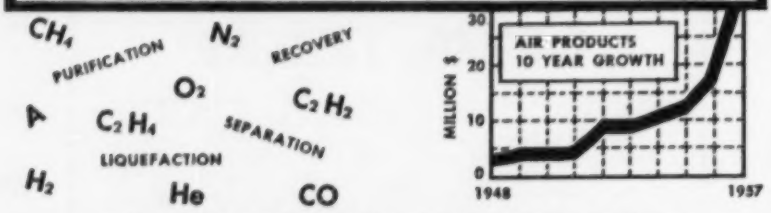

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- DESIGN ENGINEERS
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DIRECTIONS FOR USE OF CLASSIFIED SECTION

Advertisements in the Classified Section are payable in advance at 20¢ a word, with a minimum of four lines accepted. Box number counts as two words. Advertisements average about six words a line. Members of the American Institute of Chemical Engineers in good standing are allowed one six-line Situation Wanted insertion (about 36 words) free of charge a year. Members may enter more than one insertion at half rates. Prospective employers and employees in using the Classified Section agree that all communications will be acknowledged; the service is made available on that condition. Boxed advertisements are available at $17 a column inch. Size of type may be specified by advertiser. Answers to advertisements should be addressed to the box number. Classified Section, Chemical Engineering Progress, 25 West 45th Street, New York 36, N. Y. Telephone: COlumbus 5-7330. Advertisements for this section should be in the editorial offices the 15th of the month preceding publication.

people

William J. Sparks, co-inventor of butyl synthetic rubber, appointed to position of scientific advisor by Esso Research and Engineering.

Edward T. Marshall, formerly manager of project development in the Chemical Products Dept. of Esso Standard Oil Co., has been named deputy for the coordination of the world-wide chemical activities of the Standard Oil Co. (New Jersey).

Michael Markels, Jr., formerly manager, Heat Transfer Operations of the Columbia University Heat Transfer Research Facility, has been appointed to head the nuclear activities of the Atlantic Research Corp. Markels comes to Atlantic Research after five years at the Columbia facility.

Markels, Jr.

George T. Dib becomes first engigineer to pass the state nuclear engineering examination in Pennsylvania. He will engage in private consulting activities in the nuclear field.

Stauffer Chemical names **Hugh Wynn** as plant manager of their titanium tetrachloride plant now under construction in Ashtabula, Ohio.

Richard W. Robinson joins staff of Esso Research and Engineering, Planning Engineering Division.

Garrett R. Cantwell, presently manager of DuPont's Newark, N. J., pigments plant, appointed manager-designate of the company's new titanium dioxide plant under construction at New Johnsonville, Tenn.

Marion B. Geiger appointed director, general development, of Hooker Electrochemical Co., Niagara Falls, N. Y. Geiger has been general manager, Oldbury Products, since the consolidation of Oldbury Electro-Chemical Co. into Hooker last November.

Geiger

Spencer Chemical announces promotion of **Byron M. Kern** to position of general manager of production, Agricultural Chemicals Division.

Nichols

Thomas S. Nichols, president of Olin Mathieson Chemical Corp. since 1954, becomes chairman of the Board of Directors. At the same time, **Stanley de J. Osborne** is named new president of the corporation. Osborne has been executive vice-president in charge of the company's international operations.

Osborne

General Electric names **Wyman Goss** as manager of their Pittsfield, Mass., phenolics product plant. Goss joined General Electric in 1929.

Garlock Packing Co. elects two new vice presidents: **Albert J. McMullen** and **Donald F. Fraser.**

Earle S. Pedigo becomes supervisor, Viscose Section, at the Marcus Hook plant, Film Division, of the American Viscose Corp.

the chemical engineer in MARKETING

Charles J. Kentler, Jr., named New York district sales manager and **Charles B. Goff, Jr.,** will be Pittsburgh district sales manager for Rockwell Manufacturing Company's Meter and Valve Division.

Westinghouse Electric Corp. announces that **James H. Jewell,** vice-president in charge of sales, has been appointed to new post of vice-president in charge of marketing.

Sales representative in the St. Louis area for the Pfaudler Co. will be **Robert H. Schwaig.**

Olin Mathieson Chemical anounces appointment of **John F. Synan** and **Walter W. Northgraves** to the market development department of their Industrial Chemicals Division.

Spencer Chemical Co. announces appointment of **Sidney N. Gay** as general sales manager of their Industrial Chemicals Division.

New western sales manager of industrial chemicals for American Potash & Chemical Corp. will be **Ralph N. Hoh.** Hoh has been with American Potash & Chemical since 1939.

CHEMICAL ENGINEERS

Opportunities in Chemical Process Operations

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Products are synthetic fibers, films, and plastics. Locations of our eight plants—Pennsylvania, West Virginia, and Virginia. Openings are technically challenging and offer good advancement opportunities. Applications are invited from B.S. and M.S. Chemical Engineers with 1-8 years of experience. Send resumes to:

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. . . and our own staff just can't get them fast enough to keep up with our growing programs. We need Chemists and Chemical Engineers (with up to 5 years' experience) to help us in our Molecular Sieve Development work.

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- Process development
- Plant Design
- Cost estimating

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SITUATIONS WANTED

A.I.Ch.E. Members

(*Continued from page* 118)

SEASONED ENGINEER—B.S.Ch.E., M.I.T., age 45. Development project evaluation, planning, economic studies. Pilot plant design and management. Imaginative. Petroleum, ordnance, detergent experience. Fifteen years' present company. Northern New Jersey. $12,000. Box 16-6.

CHEMICAL ENGINEER—Ph.D., P.E., 37. Eight years' diversified R & D experience, including process development, statistics. Seeking technical management position. Salary in five figures. Box 17-6.

CHEMICAL ENGINEER—Ph.D.—Desire academic position in an accredited chemical engineering department with opportunities for contractual and consulting work. Ten years' responsible experience in process development and specialized experience in spray drying and crystallization. Publications and honoraries. Box 18-6.

CHEMICAL ENGINEER

desired for a position of Technical Service Engineer to advise customers on the use and operation of Girdler Catalysts. This position, in our rapidly expanding Catalyst department, offers opportunity for growth and promotion to a man with process, design or operating experience in the chemical or petroleum industries. Send resume of experience, age, academic record, salary requirements, etc., to M. B. Densford.

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JB

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the chemical engineer in MARKETING

Morgan C. Plummer has been appointed to the newly-created position of supervisor of Pydraul sales for Monsanto Chemical Company's Organic Chemicals Division. Plummer has been associated with Monsanto since 1943.

Milton Roy Co. announces appointment of **John Procopi** as sales manager. For the past four years, Procopi has been manager of market development for Milton Roy. Also at Milton Roy, **H. Rodman Smith** will be assistant sales manager.

Procopi

Rudolf Cerny named sales engineer, Aerosol Valve Division, Sun Tube Corp. Prior to his new appointment, Cerny was project engineer for Sun Tube, a subsidiary of American Can Co.

Eaton-Dikeman Co. announces appointment of **C. E. Avery, Jr.** as sales engineer. Avery comes to Eaton-Dikeman with more than eight years of sales engineering experience in the chemical and food processing industries.

P. S. Vail is now sales representative in the Chicago district office of the Chemical Division of Celanese Corp. of America.

New Dorr-Oliver offices in Pittsburgh will be headed by **Richard M. Sibley.** Sibley has been previously associated with American Cyanamid and Singmaster & Bryer.

Chemical Division of Koppers Co. appoints **John Sharp** and **Robert C. Clarke** as sales representatives in charge of new Kansas City and Twin Cities offices, respectively.

Philip H. McLaughlin, formerly head of the sales development department, has been appointed manager of sales administration at the New York office of Stauffer Chemical Co.

Necrology

J. Paul Bishop, 58, director of J. Paul Bishop & Associates, Champaign, Ill.

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100 lbs. to 8,000 lbs. per Batch!

Gives 100% uniform mix in minutes—Dry Powders, chemicals, pharmaceuticals, vitamins, dry and molasses feeds, self-rising flour and meal, cold shortening, fertilizers, insecticides. Abolishes guesswork and downtime. Modestly priced. Write for literature.

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INDEX OF ADVERTISERS

	Page
Ace Glass Incorporated	112
Aerofin Corporation	94
Air Products, Inc.	95
Aldrich Pump Co., The	16
Allis-Chalmers	27
American Air Liquide	97
American Hard Rubber Co.	34
Atlas Mineral Products Co.	96
Barnstead Still & Demineralizer Co.	106
Beckman, Inc., Arnold O.	46
Bethlehem Foundry & Machine Co.	31
Binks Mfg. Co.	64
Bishop & Co., J.	122
Blaw-Knox Company, Chemical Plants Div.	29
Brookfield Engineering Labs, Inc.	80
Cambridge Wire Cloth Co.	72
Carborundum Co., Refractories Div.	81
Carlson, Inc., G. O.	87
Chempump Corporation	35
Cole Mfg. Co., R. D.	105
Continental-Emsco Co. Div.	50
Croll-Reynolds Co., Inc.	89
Cross Roads Marine Disposal Corp.	122
Crucible Steel Co. of America	38
Curtiss-Wright Corporation	65
Davis Engineering Corp.	82
Davis Sons' Mill Machinery Co., H. C.	122
Dean Thermo-Panel Coil Div., Dean Products, Inc.	123
Doerr Glass Co.	107
Dorr-Oliver Incorporated	61
Dow Chemical Co.	83
Downingtown Iron Works, Inc.	36
Duraloy Company, The	84
Eaton-Dikeman Company	100
Eimco Corporation	12
Elliott Company	102
Fairbanks, Morse & Co.	47
Fansteel Metallurgical Corp.	101
Firestone Plastics Co.	41
Fisher Governor Co.	77
Fluor Corp., Ltd., The	52
Foram Corp., The	105
Foster Wheeler Corp.	71
Foxboro Company, The	66-67
Gas Atmospheres, Inc.	59
General American Transportation Corp., Turbo-Mixer Div.	39
Gilbert Co., L. M.	105
Girdler Company, Votator Div.	11
Graham Mfg. Co., Inc.	48
Great Lakes Carbon Corp., Electrode Div.	73
Dicalite Div.	91
Gump Co., B. F.	3
Gutehoffnungshütte	105
Hardinge Co., Inc.	113
Haveg Industries, Inc.	92
Ingersoll-Rand	8-9
Kates Co., W. A.	108
Kellogg Co., M. W., The	68
Lapp Insulator Co., Inc.	7
Leslie Company	18
LimiTorque Corp.	13
Linde Company, Div. of Union Carbide Corp.	42
Lithium Corp. of America, Inc.	51
Lummus Co., The	49
Manning & Lewis Engineering Co.	88
Metal Textile Corporation	78
Misco Fabricators, Inc.	114
Mixing Equipment Co., Inc.	*Outside Back Cover*
National Carbon Co., Div. of Union Carbide Corp.	25
Niagara Blower Co.	90
Nofsinger Co., The C. W.	104
Parsons Company, The Ralph M.	*Inside Back Cover*
Patterson-Kelley Co., Inc.	57
Petro-Chem Development Co., Inc.	43
Pfaudler Co., The	93
Philadelphia Gear Works, Inc.	13
Proctor & Schwartz, Inc.	63
Rempe Company	107
Rodney Hunt Machine Co.	79
Roots-Connersville Blower Div. of Dresser Industries, Inc.	86
Sargent's Sons Corp., C. G.	32
Schutte & Koerting Co.	107
Sharples Corp., The	75
Shriver & Co. Inc., T.	109
Sigmamotor, Inc.	123
Southwestern Engineering Co.	33
Sperry & Co., D. R.	74
Spraying Systems Co.	103
Stanford University Press	104
Struthers Wells Corporation	45
Sturtevant Mill Co.	15
Superior Tube Co.	99
Swift Glass Div., Swift Lubricator Co., Inc.	103
Syntron Company	70
Taylor & Co., W. A.	114
Texas Gulf Sulphur Co.	85
Thayer Scale Corp.	30
Thermo Electric Co., Inc.	109
Truland Chemical Co., Inc.	98
Turbo-Mixer Div., General American Transp. Corp.	39
Union Carbide Corp., National Carbon Co.	25
U. S. Electrical Motors, Inc.	103
U. S. Gasket Co., Plastics Div. of The Garlock Packing Co.	10
U. S. Industrial Chemicals Company, Div. of National Distillers & Chemical Corp.	23-24
U. S. Stoneware	260
Vapor Recovery Systems Co.	26
Virginia Gear & Machine Corp.	13
Vulcan-Cincinnati, Inc.	*Inside Front Cover*
Wallace & Tiernan, Inc.	28
Wyssmont Company, Inc.	17
York Co., Inc., Otto H.	4

C.E.P. Advertising Offices

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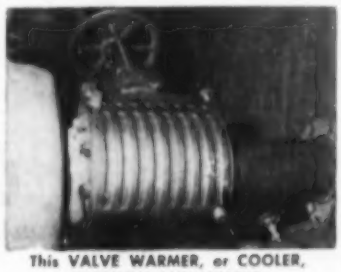

This VALVE WARMER, or COOLER, RECENTLY ANNOUNCED is receiving much favorable attention by Chemical Engineers. See our ad, page 120, of the April 1937 issue of this journal where we show a curved

DEAN THERMO-PANEL COIL

By similarly curving a Dean Panel around a valve, as shown above, we have a VALVE WARMER, often desired by Chemical Engineers for various uses where warmth is needed for the maintenance of flow of viscous fluids and liquids such as wax, asphalt, petroleum, glycerine, etc. The cost is usually much lower. Lighter in weight. Occupies less space. Simpler. More economical. No electrical hazards. The saving in time for installing makes it a decidedly preferred device.

FOR COMPLETE DATA ask for Form V-2. Also, Bulletin 355—52 pages—gives full technical information on the Dean Thermo-Panel Coil for many purposes. Bulletin 257 gives design and price data. Ask for any or all, and, if you want help on heat transfer problems, call on our specialists.

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news and notes of A.I.Ch.E.

Committee work is one of the most valuable activities of the Institute . . . The member who does not volunteer his services to a committee usually does not realize how much these groups accomplish for him. . . . As it is impossible to publish running reports on committee projects, the few lines of notice in this column or in C.E.P. often must be taken as the signal that many years of work by many members of the Institute has been brought successfully to a conclusion. . . . In this column we will try to give the activities currently engaged in by Institute committees so that the membership as a whole may know something about the programs that at present concern the chemical engineering profession. . . . **Admissions Committee,** under A. Jonnard, meets once a month to consider all applications for membership &, in addition, works with Council on reevaluating the interpretation of the Constitution in the light of Admissions Committee practices . . . A subcommittee has been appointed by Jonnard to review the committee's rules of procedure. . . . **Awards Committee,** under E. R. Gilliland, is even now voting on recipients of the William H. Walker Award, the Junior Award, & the Professional Progress Award for 1957. . . . **Career Guidance Committee,** under M. C. Throdahl, has just completed, through Raphael Katzen, a career guidance manual entitled *Opportunities in Chemical Engineering*. . . . **Chemical Engineering Education Projects Committee,** with Bob Kintner as chairman, is getting ready for the next issue of *Chemical Engineering Faculties* & has just completed a major revision of the *Chemical Engineering Problems*. . . . **Constitution and By-laws Committee,** under W. E. Lobo, is currently reviewing a by-law change proposed by Council in the student area. . . . **Education and Accreditation Committee,** R. A. Morgen, chairman, has taken action on the chemical engineering curricula at twenty schools . . . A new definition of the chemical engineering curricula to be accredited is to be presented to Council for action in June. . . . **Equipment Testing Procedures Committee,** C. H. Brooks, chairman, is the proud originator of three testing procedures . . . So far this year two have been issued, on absorbers & condensers, the latter being the second standard to come out of the Heat Exchange Subcommittee . . . Currently the committee has projects underway on agitators, corrosion, distillation, driers, evaporators, & pumps. . . . **Ethics Committee,** W. I. Burt, chairman, is not, we are happy to report, considering any problems . . . This committee is composed exclusively of past presidents. . . . **Executive Committee,** J. H. Rushton, president, has been meeting about once a month since the beginning of the year to conduct Institute business assigned to it by Council . . . Its problems are varied & often it calls in for advice special committees of the Institute. . . . **Fiftieth Anniversary Committee,** C. G. Kirkbride, chairman, is a special committee organized to handle the celebration of the Fiftieth Anniversary of the Institute, June 22-27, 1958, in Philadelphia . . . It is well along in its plans & the week-long program promises to be an event that will be long remembered by those who attend. . . . **Institute Sections Committee** has been extremely busy under J. C. Dart, chairman . . . Its job is to consider applications from groups of chemical engineers for chartering of local sections & also to review by-laws . . . This year the Syracuse, New York, group has been recommended for local-section status. . . . **Membership Committee,** J. J. McKetta, chairman, is trying to get 2,000 new members for 1957 . . . We have spoken about this many times in this column & every local-section member is well aware of the intensive drive that this group is conducting to increase membership broadly throughout the profession. . . . **Nominating Committee** is at this point considering a list of candidates suggested by petition & also in committee &, as outlined last month, the slate of candidates will be available by July 15 . . . W. G. Whitman, chairman, is at present in Japan. . . . **Pollution Control Engineering Committee,** Roy Weston, chairman, recently advised Council of the feasibility of A.I.Ch.E. being one of the sponsors of American Sanitary Engineering Intersociety Board . . . A subcommittee of this committee arranged a portion of the program for the Air Pollution Control Association Golden Jubilee Meeting on June 2-6, 1957 . . . One of the members, C. A. Bishop, is our representative to the E.J.C. Committee on Air Pollution. . . . **Professional Development Committee,** under F. E. Reese, is one of our most active groups . . . In January it had a long session with Council, reporting on many of its plans for future exploration in the professional area . . . None of the projects are far enough along to report on formally, but every one of the members of this committee is enthusiastic about the potential . . . . The rest of the committees so ably serving the profession will be reported on in this column next month.

F.J.V.A.

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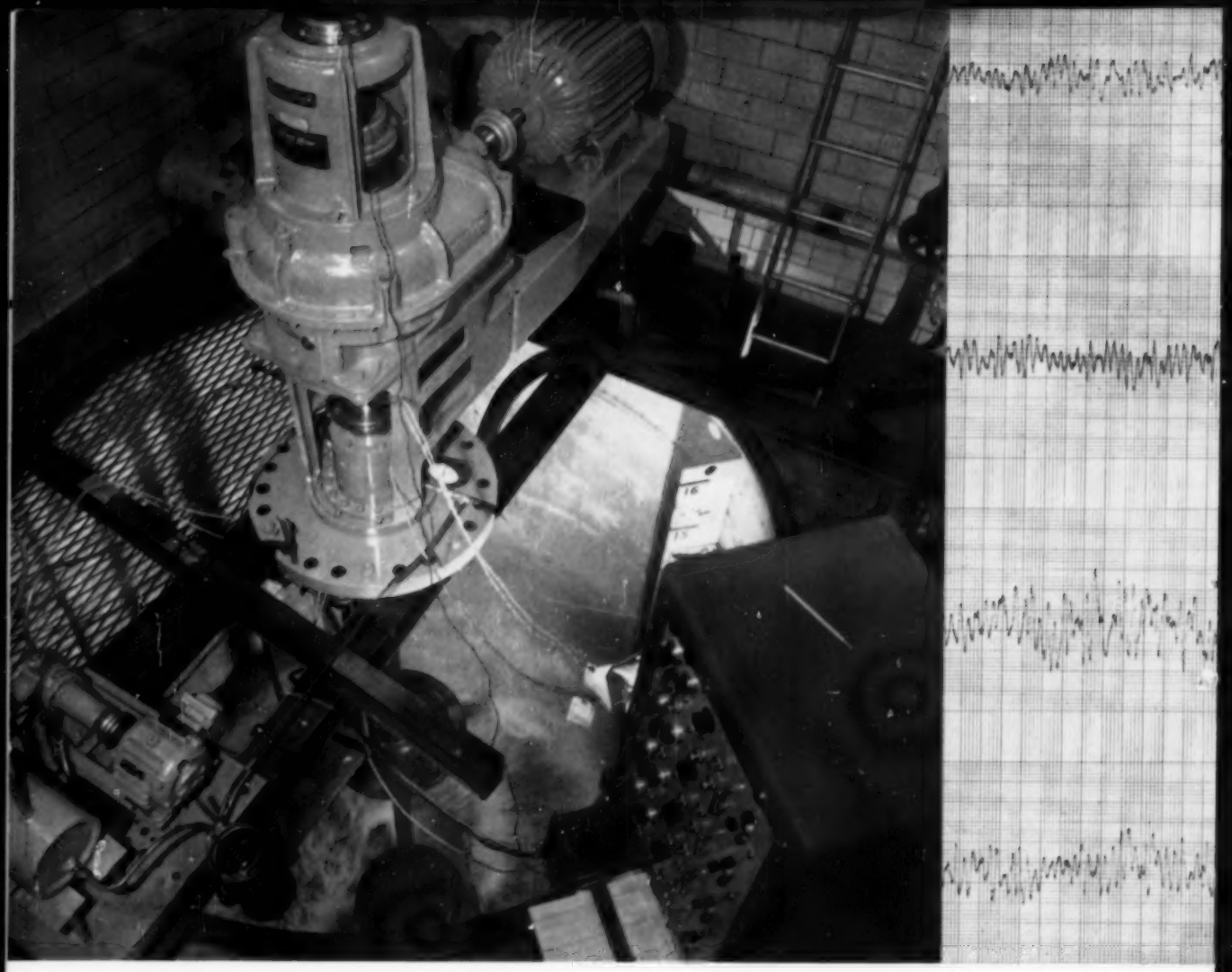

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